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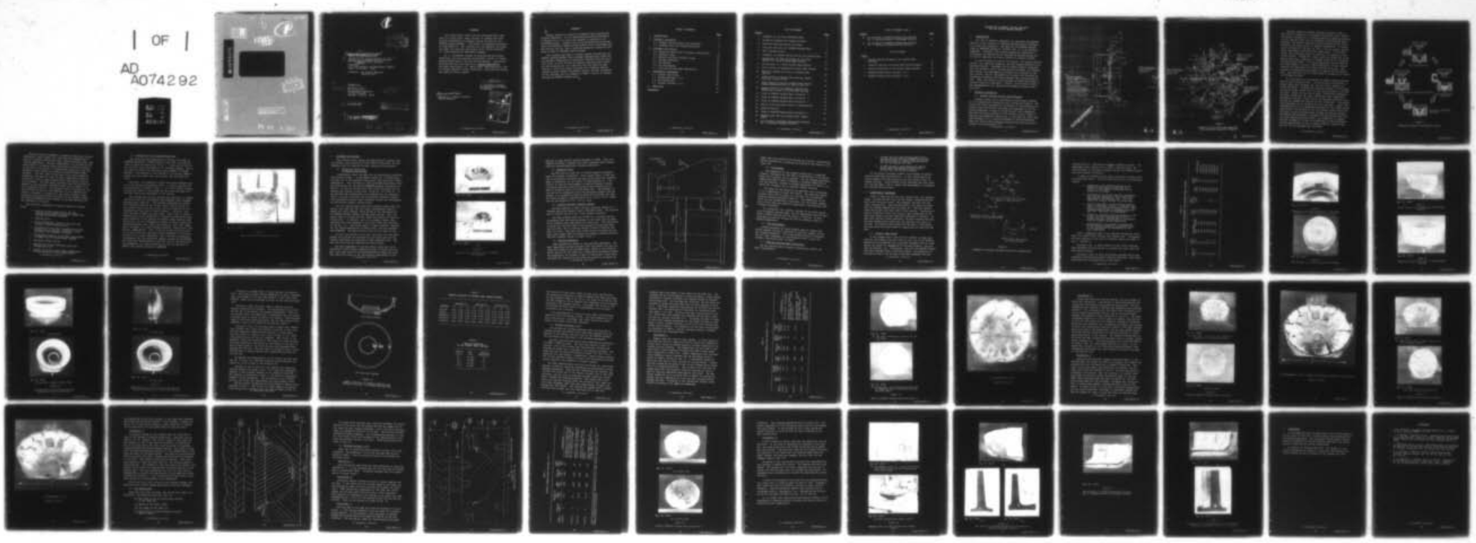

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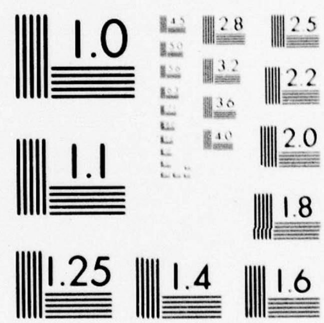

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Report No. IITRI-B6151-12

6 FEASIBILITY OF SQUEEZE CASTING THE BASE
FOR THE PATRIOT WARHEAD XM248E1.

Commander
U.S. Army Research and Development Command
Dover, New Jersey 07801

Attention: Mr. Wilford Montross
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10

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FOREWORD

This final report covers the work performed from 1 May 1978 to 31 March 1979, under Contract No. DAAK10-78-C-0176, entitled "Feasibility of Squeeze Casting the Base for the PATRIOT Warhead XM248E1." The report is designated internally as IITRI-B6151-12. This contract with IIT Research Institute was under the technical supervision of Mr. Wilford Montross, U.S. Army Research and Development Command.

Mr. S. Storchheim, Manager of Metalworking and Foundry Technology, was the principal investigator, and Mr. M. Virani, Research Metallurgist, was the Project Engineer. Substantial contributions were also made by Mr. Ambika Chakravartty, Assistant Metallurgist; Mr. Dennis Woods, Experimentalist; and Mr. Anthony Omotosho, Senior Technician. The report was edited and typed by Violet Johnson.

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ABSTRACT

Squeeze casting is a hybrid of permanent mold casting and forging techniques. In this metalworking process molten metal is metered into a die cavity and pressure is applied to the solidifying metal. Suitable use of the optimized process parameters can eliminate common casting defects such as shrinkage and gas porosity and can lead to improved mechanical properties over those of sand or permanent mold castings.

This program was aimed at squeeze casting the base for the PATRIOT warhead XM248E1 from a wrought aluminum alloy (6061 Al). The possible enhancement of properties resulting from the use of this alloy, as well as from the squeeze casting process itself, and the potential for cost reduction were two areas of major interest. This final report describes the equipment and the squeeze casting tooling, procedural details, and the evaluation of the castings, and is a summary of IITRI's results in squeeze casting the PATRIOT warhead base.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (cont.)

LIST OF TABLES

FEASIBILITY OF SQUEEZE CASTING THE BASE
FOR THE PATRIOT WARHEAD XM248E1

1. INTRODUCTION

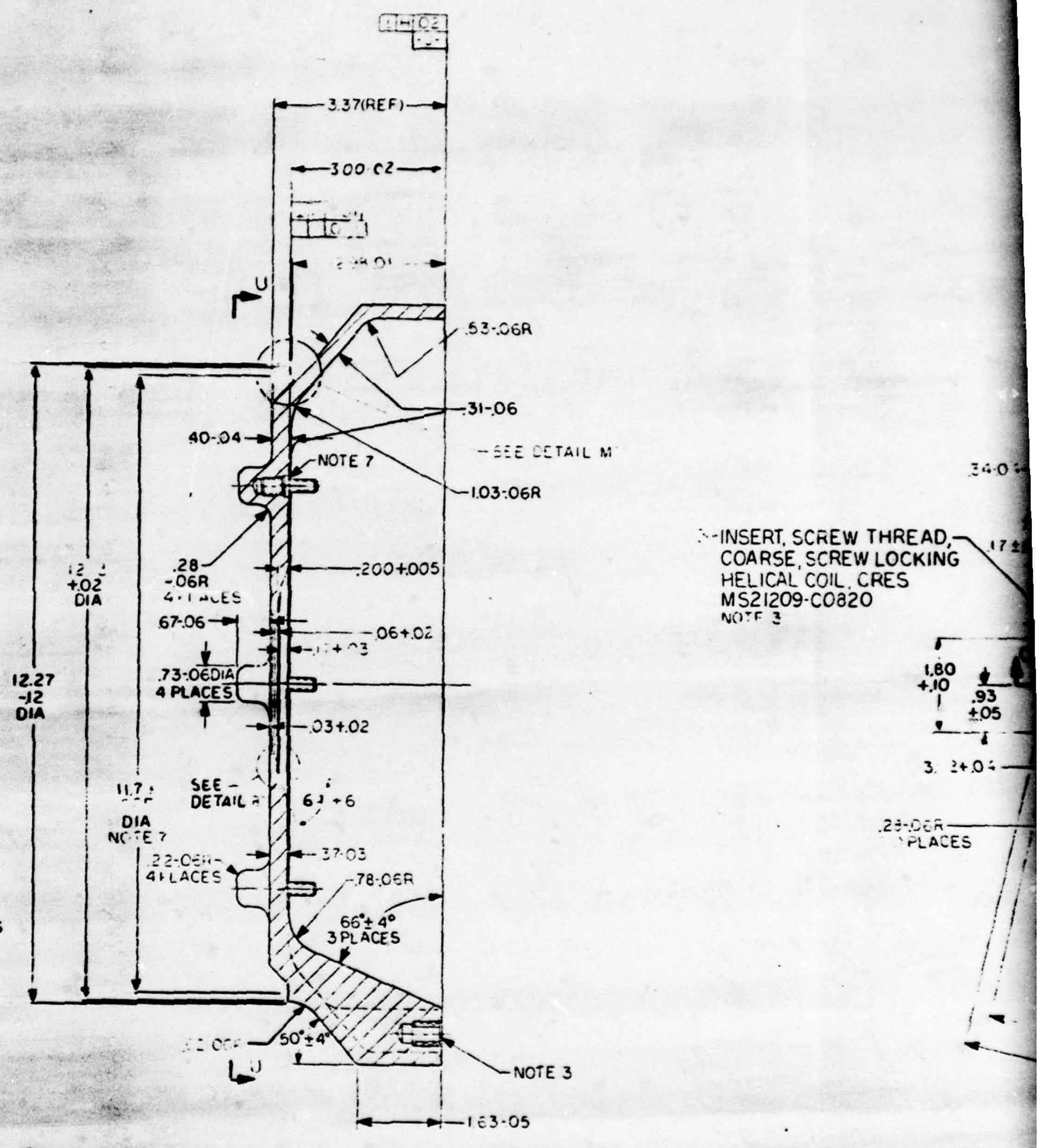
The cost of ordnance components has increased considerably. There is a vast interest in improving manufacturing techniques to achieve cost reduction. The base for the PATRIOT warhead shown in ARRADCOM drawing No. 9278872 (Fig. 1) is an expensive component. Therefore, the subject program was undertaken to investigate the feasibility of reducing the manufacturing cost as well as improving the product quality by squeeze casting.

In the following section of this report, the squeeze casting process, the candidate component, and the program objectives are described briefly. Equipment and procedural details concerned with the hydraulic press, melting and melt transfer, die heating and coating, and experimental procedures are presented in the next section, and the subsequent section goes into detailed experimental procedures and related matters and tooling modification. Then, the quality of the castings evaluated according to various criteria is described. Finally, the principal results and recommendations for improving the squeeze casting process are given.

2. TECHNICAL DISCUSSION

2.1 Squeeze Casting Process and Advantages

Squeeze casting can be described as liquid metal forging or as a combination of permanent mold casting and forging. The process has been developed for the purpose of counteracting the disadvantages and further extending the advantages of the die casting technique in order to produce better cast components. Much work has been conducted on the process, both in terms of research and commercial application, in the USSR for quite some time although it is a relative newcomer in the United States. There are various publications discussing the major facts pertaining to the techniques.[1-5]



NOTES:-

1- SPEC MIL-A-2550 APPLIES.
2- MATERIAL: ALUMINUM ALLOY A356 SPEC MIL-A-21180C
3- ALL INSERTS SHALL BE BELOW SURFACE AS SHOWN IN SECTIONS [illegible] & G-G.
4- DRAFT ANGLE 2° MAX UNLESS OTHERWISE NOTED
5- MACHINE SURFACES 125 ✓ ALL OTHER SURFACES 250 ✓ AS CAST.
6- CLASSIFICATION AND INSPECTION OF CASTING SHALL BE IN ACCORDANCE WITH SPECS MIL-C-6021G CLASS IA GRADES B & C & MIL-A-21180C, CLASS 1 & 12.
7- MACHINE BASE FOR [illegible] FIT WITH [illegible] PART NO 9312566 AT ASSEMBLY OF METAL PARTS NO. 93125[illegible] [illegible] PARTS ARE [illegible]
8- STAMP PART NO [illegible] WITH [illegible] HIGH CHARACTERS, LOCATE [illegible] WHERE SHOWN

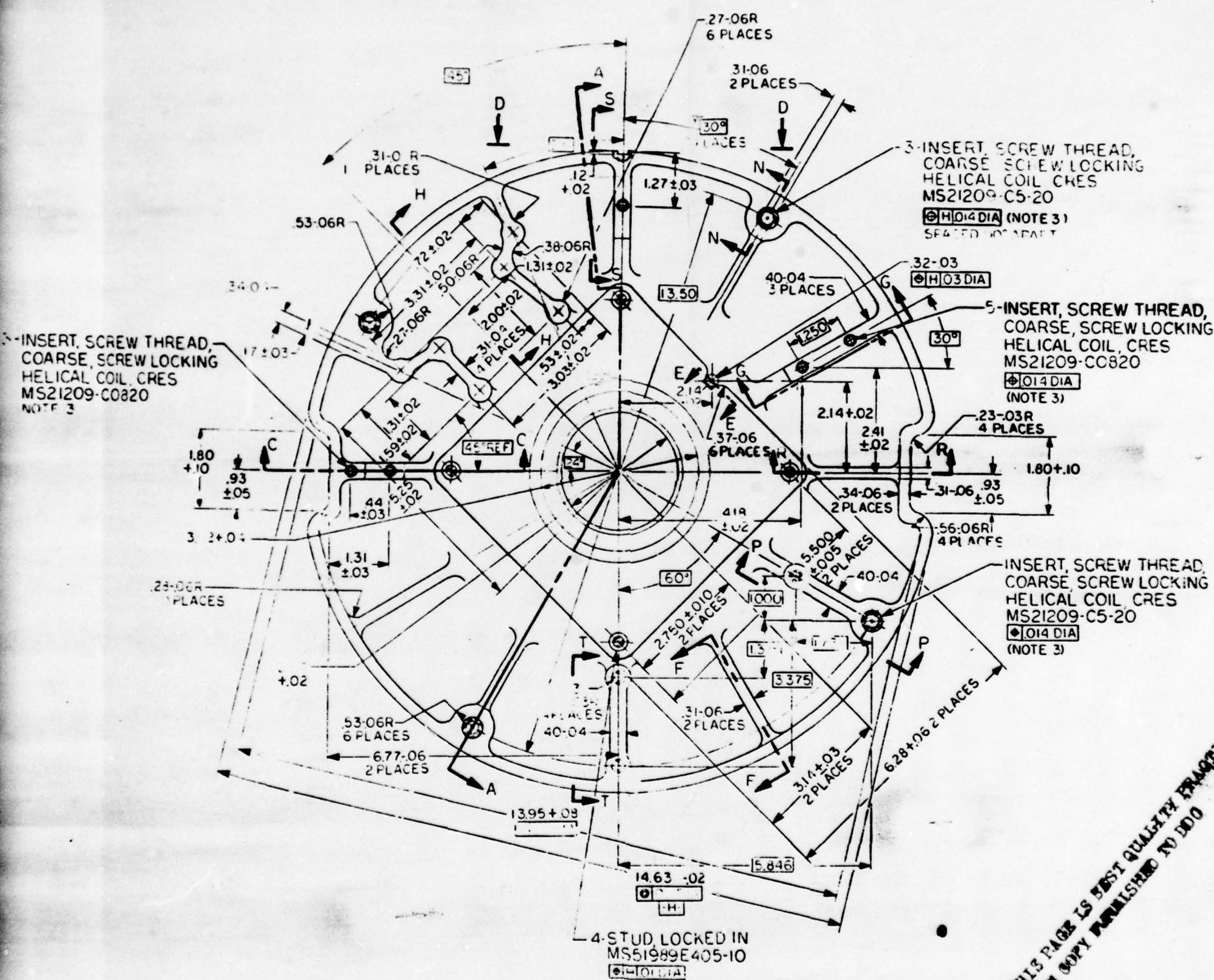


Figure 1

Schematic of the Finish-Machined Base
(From ARRADCOM Drawing No. 9278872)

The four stages of squeeze casting are shown in Fig. 2. They consist essentially of pouring molten metal into a female die cavity, allowing it to solidify partially, applying pressure to fill the die cavity and to accomplish solidification under pressure, and finally removing the casting from the die cavity. Initially the molten metal is somewhat superheated. A certain time is allowed for the melt to cool in the die cavity, during which time partial solidification takes place. In the third stage, the solidifying metal is subjected to pressure to fill the die cavity. During this stage, gases are eliminated in the molten metal and a reduction in volume occurs due to shrinkage cavities being formed. The surrounding metal contains much of the liquid phase, so that a timely application of the required pressure can feed metal into these cavities with ease. The pressure is maintained long enough to complete the solidification. The pressure level is high enough to eliminate all traces of shrinkage porosity.

It is necessary to distinguish the squeeze casting process from the die casting process. In die casting, molten metal is forced under great pressure into the die cavity through the runner and gates. Although the injection pressure is very high, the molten metal freezes first at the narrow entrance to the die cavities. Except in the case of small, thin-walled components, the metal inside the die cavity solidifies under essentially atmospheric pressure, which results in shrinkage porosity in the casting and renders the quality of the casting poor. The mechanical properties of the products are also very poor. Again, considerable metal loss is experienced because of the runner system. Additionally, the problem of die life becomes severe because of the need to push the molten metal through the narrow openings. Considering the principle of squeeze casting operation and various other aspects discussed below, the capability of squeeze casting is superior to that of conventional casting techniques in many applications so far as product quality, product size, and cost of the equipment are concerned.

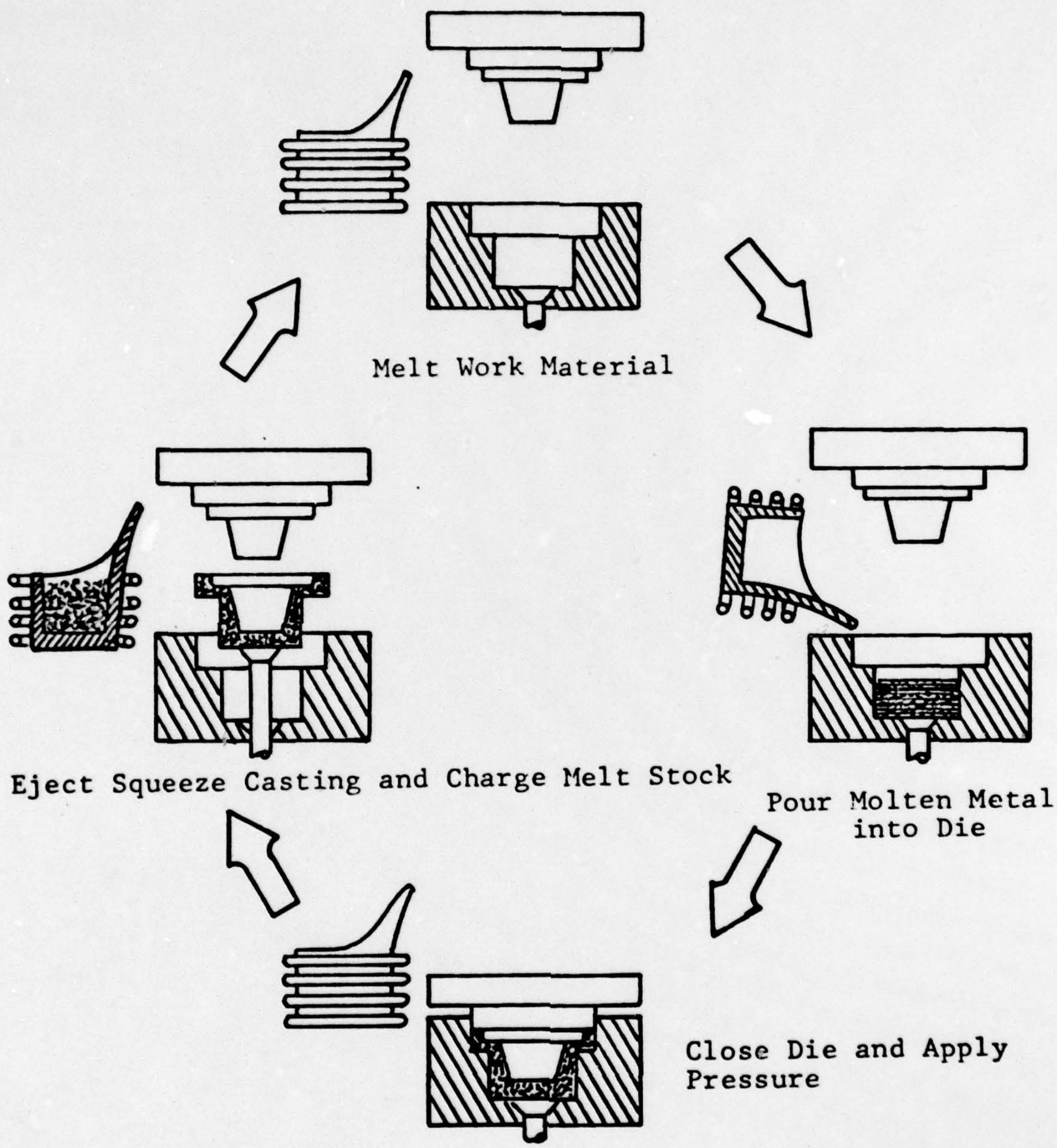


Figure 2

Production Sequence for Squeeze Casting

The main process parameters in squeeze casting are the melt temperature, metal volume, the time delay for application of pressure, pressure application time, squeeze-pressure level, and tooling temperature. The melt temperature is to be kept low because there is no gating system and because filling of details in the mold or die cavity is accomplished primarily by the displacement of the molten or partially solidified metal under pressure. This will lead to fine grain size, good mechanical properties, and good die life, but melt temperature should be sufficient to give a good surface finish and internal quality to the product. The time delay should be such that pressure is applied to the partially solidified metal and not while it is still completely molten. The pressure level is affected by the work material as well as the complexity of the component and should, in general, be selected at the lowest possible level consistent with good internal structure of the squeeze casting. The tooling temperature also depends on the work material and the complexity of the part.

The principal advantages of squeeze casting are listed below:

1. Ability to form complex parts and thin sections which cannot be done in conventional forging and casting techniques

2. Improved yield

3. Closer dimensional control of the part and therefore reduced machining cost

4. Elimination of the labor associated with sand casting such as molding, trimming of risers and gates, and cleaning of casting

5. Substantial reduction in pressure requirements in comparison with conventional forging

6. Excellent surface finish

7. Possibility of high production rates and reduced unit cost

8. Ability to use cast and wrought compositions of work materials in many applications.

2.2 Candidate Part and Program Objectives

The finish-machined dimensions of the base are shown in ARRADCOM drawing No. 9278872 dated 14 July 1975, the main portions of which are shown here in Fig. 1. There are 12 ribs on the interior of the pan-shaped 15 in. diameter casting. Ten of the ribs are radial, and two have a more complex "Z" shaped geometry. The exterior of the casting is of circular symmetry except for eight small ribs, two notches, and four pads for studs.

Currently, the component is made from A-356 aluminum alloy as a sand casting with graphite chill. A typical casting with risers and gates is shown in Fig. 3. As in any similar casting, the material yield is low because of the risers and gates and the heavy machining requirement on the casting.

This program was aimed at showing the fesibility of squeeze casting the base for the PATRIOT warhead XM248E1 from a wrought aluminum alloy (6061 Al). The possible enhancement of properties resulting from the use of this alloy, as well as due to the squeeze casting process itself, and the potential for cost reduction were two areas of major interest. Initially, this study had been divided into four tasks: Task 1 was to involve demonstration of the feasibility of squeeze casting with liquid metal extrusion in the complex rib details using subscale simulating dies, but was subsequently dropped in view of additional experience gained (Ref. IITRI letter dated 15 June 1978, Addendum to Proposal No. IITRI-78-108B (Revised), Attention Ms. Rose Narcise, DRDAR-PRW-B). Task 2 involved design and fabrication of the full-scale dies and other backup equipment for the manufacture of the target components; Task 3 involved optimization of parameters for the successful squeeze casting of the PATRIOT base from 6061 aluminum alloy; and Task 4 was to use these optimum parameters in a small production run for the delivery of twenty (20) squeeze castings to ARRADCOM.

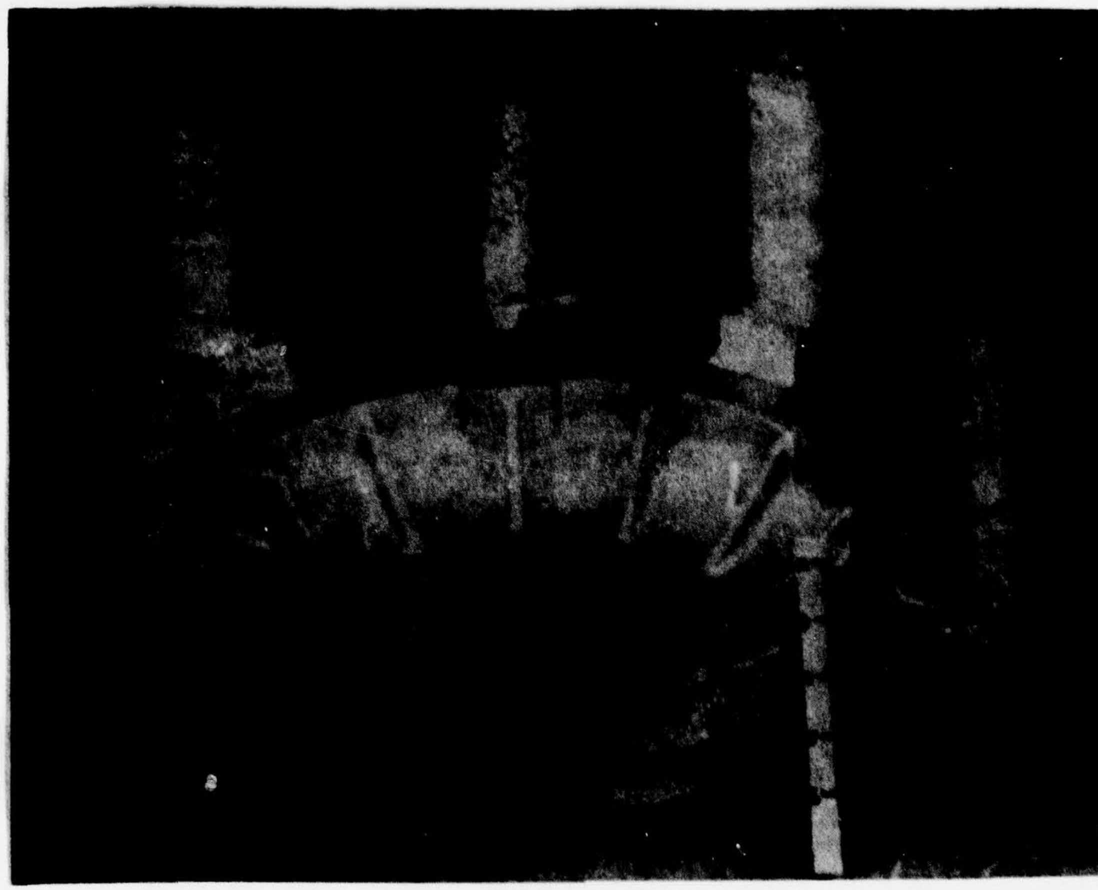


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Figure 3

Sand Cast Base with Risers and Gates

3. EQUIPMENT AND TOOLING

This section covers design and fabrication of squeeze casting tooling, some discussion of the 1000-ton HPM press, and the equipment used for melting the 6061 aluminum alloy material.

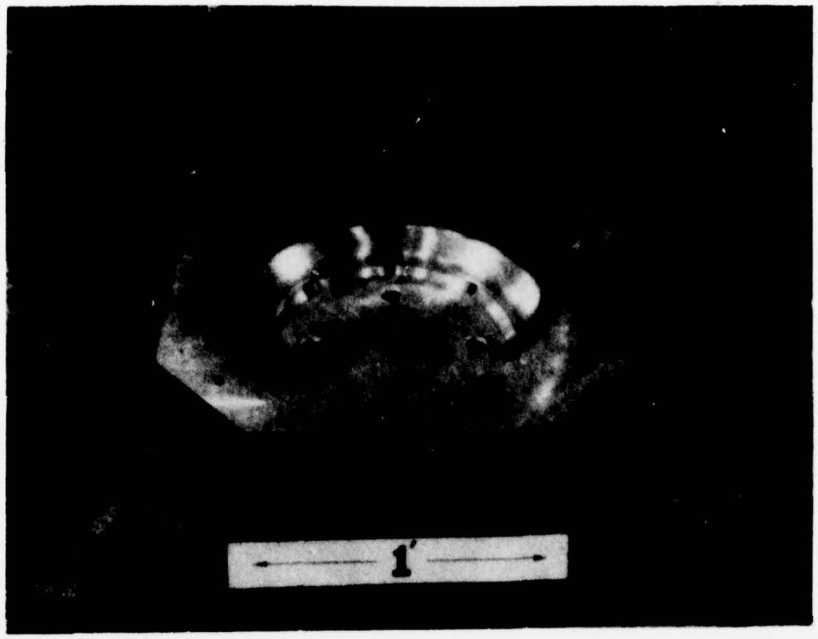
3.1 Design and Fabrication of Squeeze Casting Dies

A substantial search was made for die fabrication quotations from several vendors. A preliminary search for a tooling manufacturer led to one extremely high verbal quote which was totally unacceptable. This related to a shop doing EDM processing, which was prohibitive for the complex ARRADCOM squeeze casting die required. In view of the fact that very close tolerances are not required for squeeze casting dies, ±0.003 in. to ±0.004 in., it was decided that conventional tool machining was not necessary; rather, casting of the dies was considered a perfectly acceptable alternative whereby their tolerance control was satisfactory and fell within squeeze casting limits.

Two tool casting shops were found (several others were contacted, but could not cast the large, approximately 1200 lb female die cavity needed), which quoted on the fabrication of the PATRIOT warhead squeeze casting punch and die. Both companies came in at about $15,000, which fell exactly on the predicted costs. In addition, one of the vendors, Sarcol Corp., indicated they were planning to stay with IITRI after delivery of the die, i.e., they would modify it where required. Approval for the tooling manufacture by Sarcol Corp. was also obtained from ARRADCOM. The punch and the lower die are shown in Fig. 4.

At first the pattern of the upper and lower die were made taking into account the tolerances on the final part and the thermal coefficient of expansion of 6061 aluminum alloy. The dies were cast and then machined and heat-treated.

The main components of the die system, which were to be subjected to high surface temperatures due to contact with the melt, were made from H-13 chrome-molybdenum hot-work die steel. This choice was based on the satisfactory performance of the



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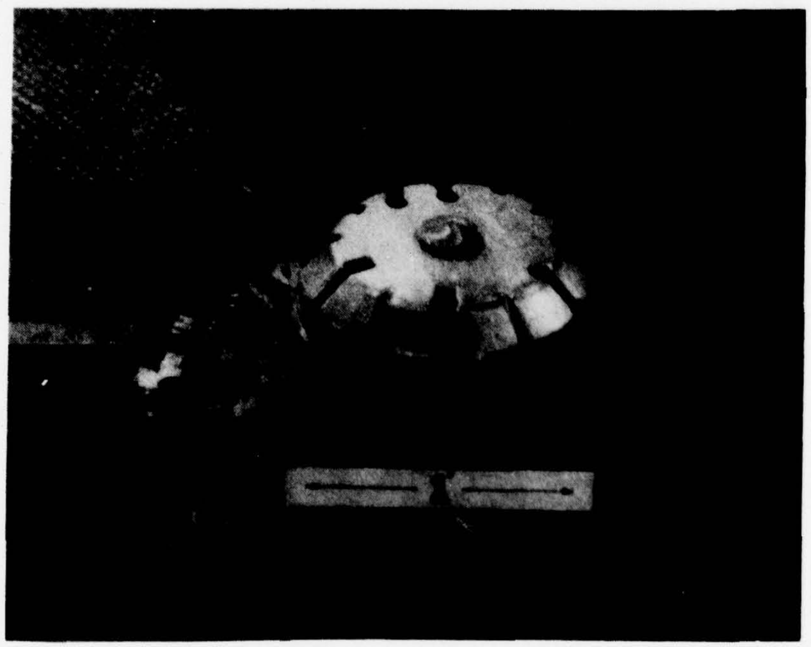
(a)



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(b)

Figure 4

Lower Die (a) and Punch (b) for PATRIOT Warhead Base

material in past squeeze casting programs at IITRI. This is a commonly available, standard die steel possessing good thermal shock and medium-temperature strength properties.

3.2 Hydraulic Press

The HPM 1000-ton press has a variable-capacity hydraulic pump and nitrogen accumulator. Press speeds from 0 to 600 rpm can be achieved by operating the press with either the hydraulic pump or accumulator as the supply of high-pressure oil. The control of load and ram movement is achieved manually during slow-speed operations and electrically with switches and hydraulic pressure sensors for high-speed work. The movement of the ram can be stopped and also the ram speed changed from fast advance to a preselected speed by electrical switches and cams. The press daylight is approximately 48 in. with a 24 in. stroke, and the bed measures 50 in. x 42 in. wide.

3.3 Furnaces and Melt Transfer System

The main furnace in which the melt stock was melted is a Lindberg gas-fired furnace rated at 860,000 Btu/hr. The crucible used to contain the melt was a clay graphite crucible.

The 6061 aluminum alloy was melted in a crucible and was transferred from the melting furnace to the press area by means of an overhead crane and placed on a ladle cart. The ladle could be moved into the work area of the press by rolling the ladle cart on rails, and it could be quickly tilted to transfer the melt into dies. The ladle cart could then be retracted and the press ram brought down to initiate the squeeze casting operation. The melt transfer system is shown in Fig. 5.

3.4 Melting Techniques

6061 aluminum was melted in the oxidizing atmosphere. The melt temperature was kept between 1300° and 1600°F, and the crucible was lifted by the overhead crane, walked to the 1000-ton press, and set in the ladle cart fitted with a preheated launder. The temperature was allowed to drop to some extent, after which the metal was poured into the lower die cavity by bringing the

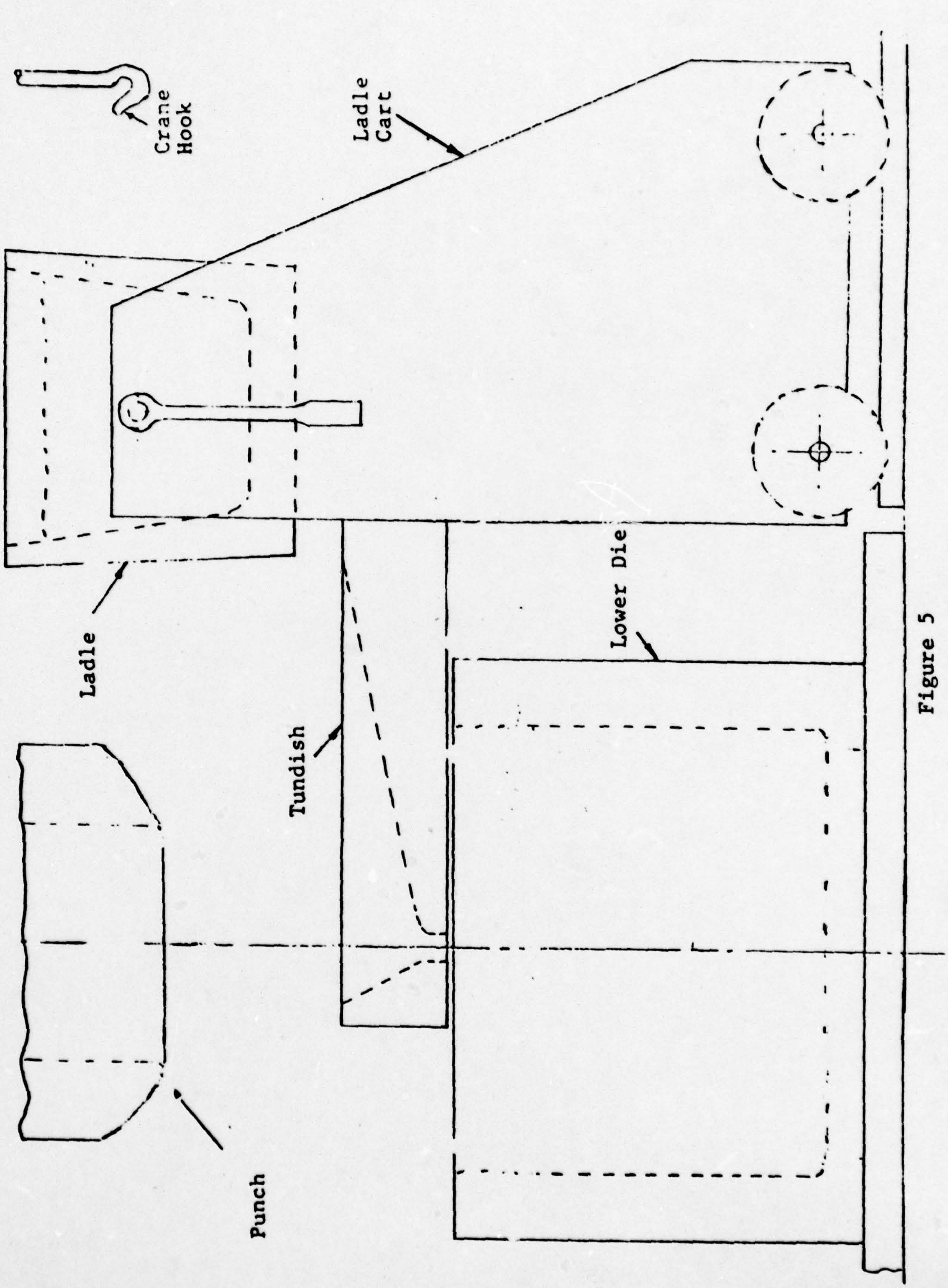

Figure 5
Melt Transfer System

ladle cart into position and tilting the crucible, transferring molten aluminum into a pouring cup located at the center of the lower die.

3.5 Die Heating

The temperature of the squeeze casting die is important because a preheated die will delay solidification of the molten metal until pressure can be applied. But the maximum preheating temperature must be below softening or drawing temperature of H-13 die material, whereas a minimum temperature of 350°F is required for toughness and to minimize thermal stresses.

The lower die was heated by an induction coil surrounding it to a temperature of about 400°-500°F. The punch was heated to about 350°-450°F by means of a portable set of seven gas burners arranged uniformly around it. The temperature of the lower die was automatically controlled, but the proper temperature of both dies was ensured by measuring it periodically with a surface pyrometer.

In a production run, however, because of the quick succession of squeeze castings made, the die temperature could be maintained without heating once the series is started. In fact, there may be need for cooling the dies to maintain them at a desired temperature.

3.6 Die Pretreatment

Freshly machined die steel surfaces must be conditioned before squeeze casting to minimize the galling tendency of the hot aluminum workpiece. This conditioning consists of heating the die steel components to approximately 600°F to give the surface a protective layer of oxide.

3.7 Lubricant/Parting Agent Application

The die coating used in squeeze casting must fulfill two basic requirements:

1. It must act as a good parting agent by preventing intimate contact between the die and the molten metal to inhibit welding between the two and improve die life.

2. It must provide a good lubrication during molten metal displacement prior to die filling and also during stripping.

Of the various coatings studied, only Aquadag in aqueous solution performed satisfactorily. It was a water-based colloidal graphite and was sprayed on the die surfaces prior to squeeze casting. Alcohol-based zircon lubricant was also tried as a parting agent, and it showed some improvement in stripping the casting from the punch.

4. EXPERIMENTAL PROCEDURES

Figure 6 shows how the part was squeeze cast, the sequence being: pouring the melt into the die center, lowering the top punch onto the molten metal, and "forging" the melt into the final configuration. Upon solidification, the punch is raised and the casting removed from the upper die. The full details about the process are dealt with in this section. Pouring accurately, duration of pour into the die, and cleanliness of the melt were found to be very important parameters to control. To make sure the melt poured precisely, the pour crucible and launder were mechanically locked into the position just prior to casting. To prevent slag flowing with the melt, a mica filter was used which was found useful in separating the slag from the melt.

4.1 Forward Dome Trials

It was thought that a part which is similar in shape (except for the complex ribs) and close to the size of the PATRIOT warhead should be squeeze cast using 6061 aluminum alloy to study mainly the extent of segregation of alloying elements, the pattern of porosity, etc. Fortunately, dies for the PATRIOT forward dome were available from a previous project, and permission to use them to make a few castings using 6061 aluminum alloy was

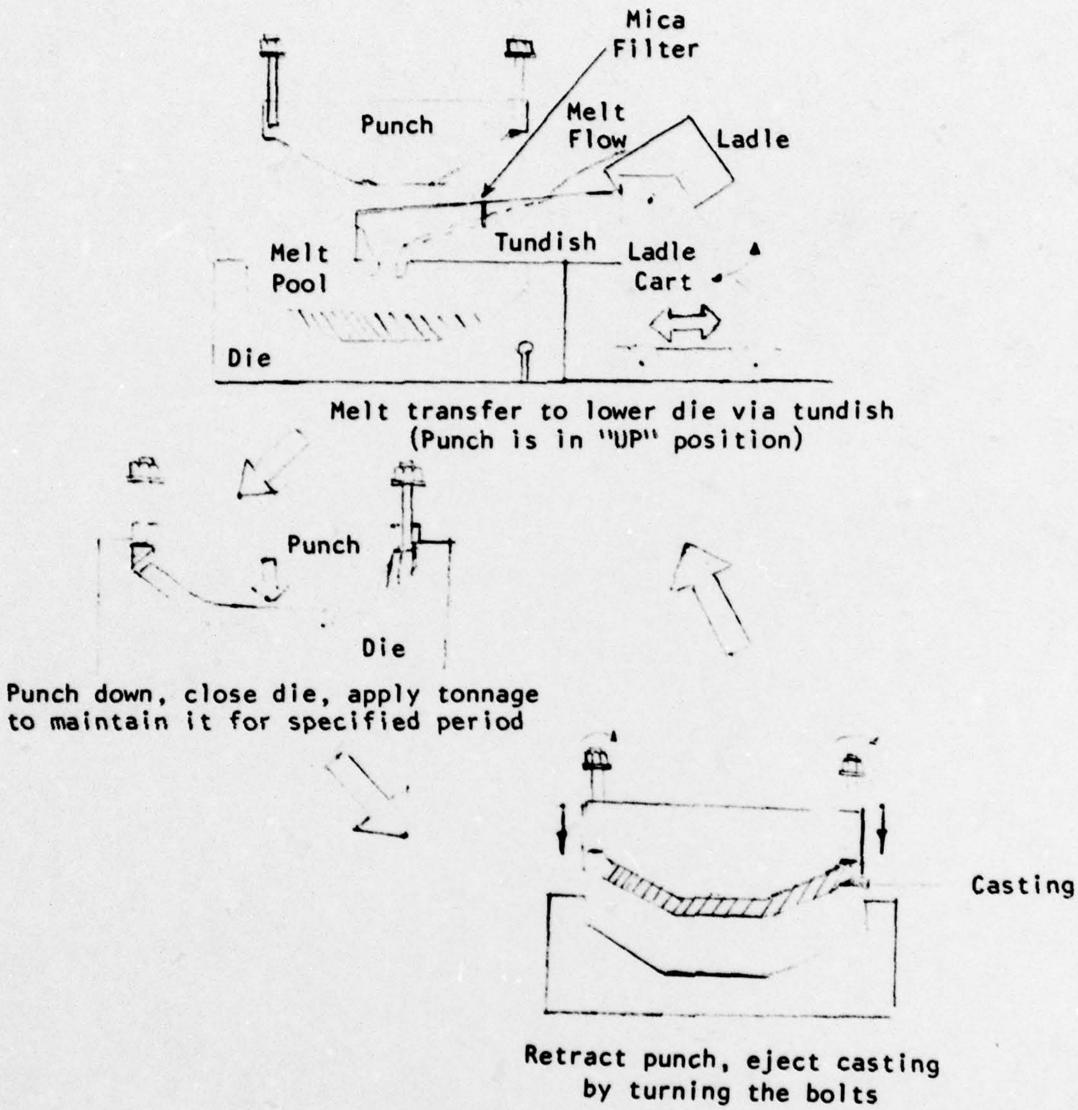

Figure 6

Schematic of Squeeze Casting Process for Warhead Base

obtained from U.S. Army Missile Command, Redstone Arsenal. The experiments were carried out in IITRI's 1000-ton press, and proved helpful in eventually squeeze casting the PATRIOT warhead base with complex rib details.

A number of PATRIOT forward domes were made by squeeze casting using 6061 alloy. This was done basically for the following reasons:

a. Similarity of the PATRIOT warhead to the PATRIOT forward dome in shape and size, except for the complex rib pattern on the inside of the former.

b. Optimization of certain important parameters, like pouring temperature, press dwell time, magnitude of the pressure, etc., to save time while squeeze casting the actual part.

c. Study of the effect of the melting practice such as oxidizing, neutral, or reducing atmosphere in the furnace during melt-down. Melt cleaning methods such as skimming or filtering, etc., also must be investigated.

d. Attempt to correlate cracking tendency in the sleeve area and shrinkage cavity in the thicker sections, particularly at the center, with the squeeze casting temperature.

e. Determination of the extent of segregation of the alloying elements in different areas of the casting and its dependence on the pour temperature.

Table 1 summarizes some of the important parameters under which the forward dome castings were squeeze cast. Photographs of these castings in part and at different angles are shown in Figs. 7 through 12.

Casting 6 (Fig. 7) shows defects on the inside resulting from incomplete die filling due to insufficient melt stock and some slag inclusions.

Casting 12 (Fig. 8) shows gas porosity perhaps due to gas absorption during melting under reducing conditions; lower dwell time might also be responsible for the defect.

Table 1

SQUEEZE CASTING PARAMETERS FOR FORWARD DOME CASTINGS

Casting No.	Melt Stock, lb	Die Temp., °F Core	Die Temp., °F Cavity	Pour Temp., °F	Wait Period in Die, sec	Load, tons	Dwell Time, sec	Lubrication
6	19	400	500	1300	-	1000	30	Graphite
12	20	450	600	1300	-	1000	20	Graphite
17	20	450	450	1300	-	1000	60	Graphite
19	20.8	450	450	1300	2	1000	60	Graphite
21	21	450	450	1300	15	1000	60	Graphite
24	21.5	450	450	1500	2	1000	60	Graphite
25	21.5	450	450	1500	2	1000	60	Graphite

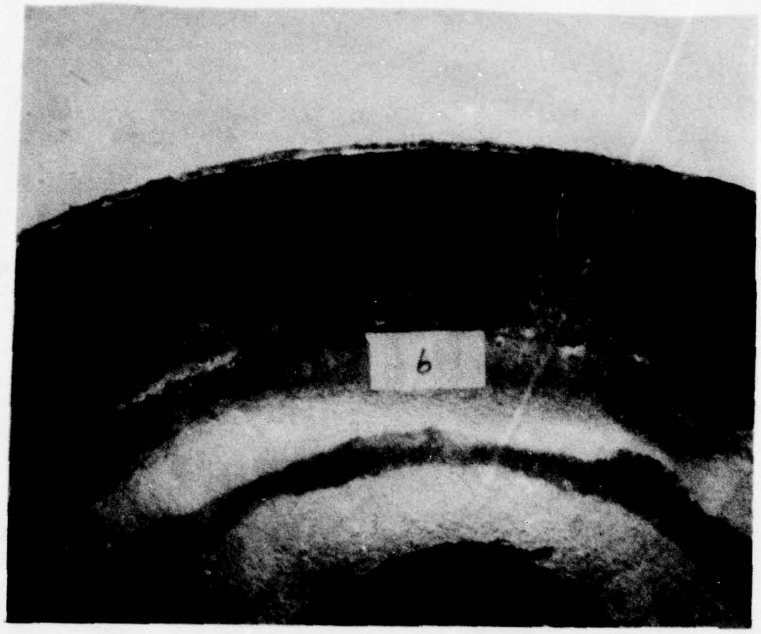

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Figure 7

Depressions and Slag Inclusions on the Inner Surface of a Trial Forward Dome Casting

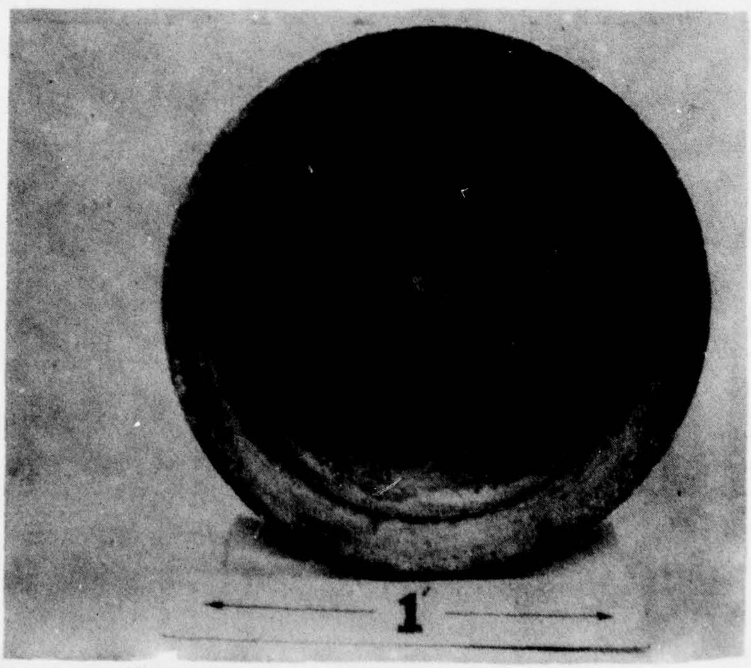

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Figure 8

Gas Porosity in a Trial Forward Dome Casting

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Figure 9

Cross Section of a Sandblasted Forward Dome Casting

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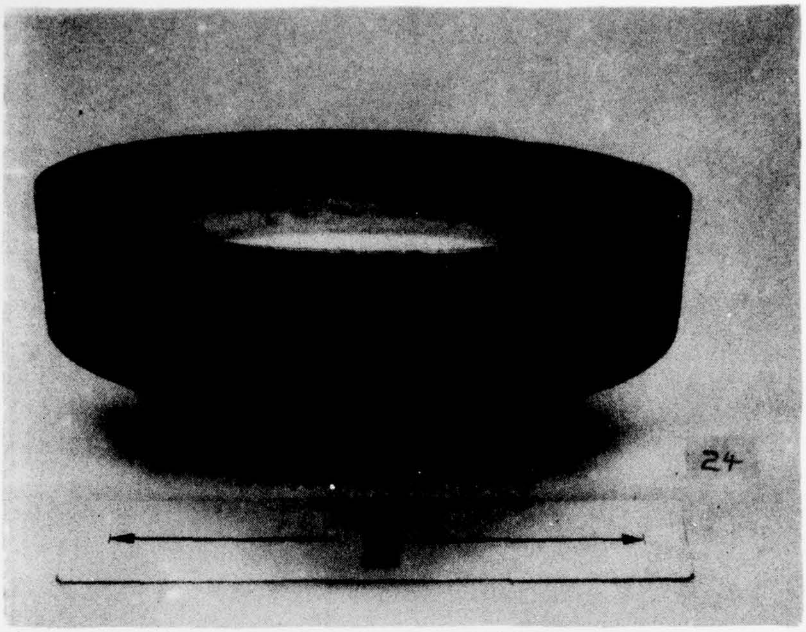
Figure 10

Defective Surface and Crack in Forward Dome Casting



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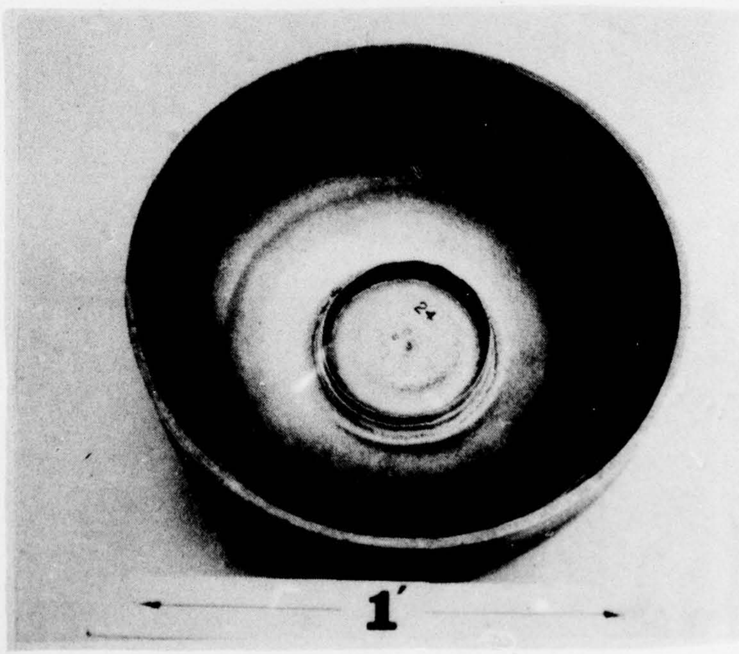
(a) Side view



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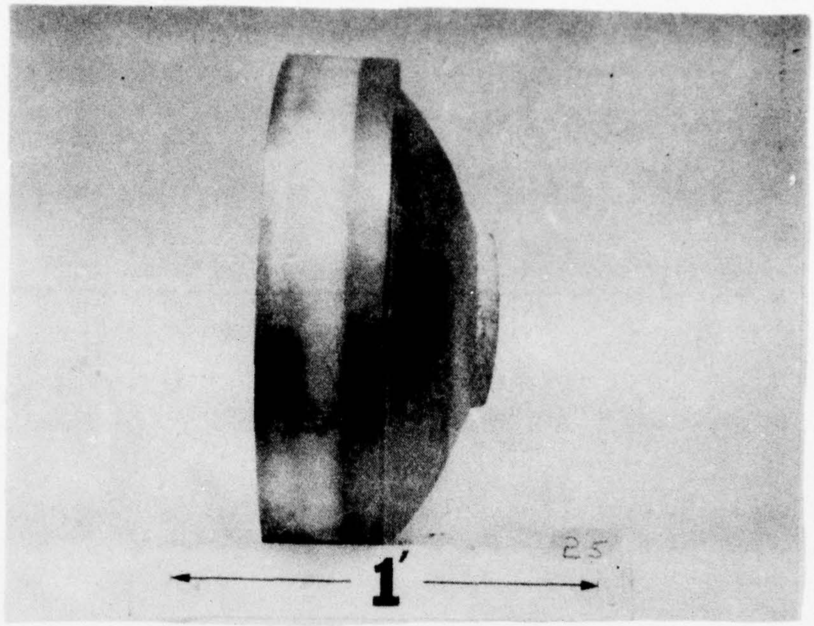
(b) Top view, showing inner surface

Figure 11

Clean Surface of Forward Dome Casting, Defect-free Due to Mica Filter



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(a) Side view

Neg. No. 49544

(b) Top view

Figure 12

Clean Surface of Another Forward Dome Casting, Showing Reproducibility of That in Fig. 11

Casting 17 is shown (Fig. 9) after the part was sawed in half. The rather cleaner surface appearance is due to sandblasting, even though it still has some porosity in the skirt area. However, there are no shrinkage cavities in the cross-sectional area.

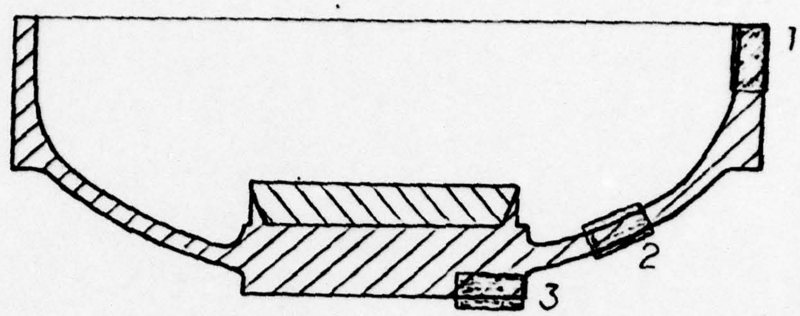
Casting 21 (Fig. 10) looks like an extreme case of a squeeze casting full of defects. The molten metal was held in the die for 15 sec before the pressure application. This not only brought down the temperature substantially but also caused a thicker layer of oxide to form on the surface. Some slag also seems to have been mixed with metal, and all these factors have combined to give a very defective surface and cracks.

Casting 24 (Fig. 11) was made using a higher pour temperature (1500°F) and a short hold period in the die (2 sec), but the most important difference was the use of a mica filter. The mica filter is simply a thin sheet of mica 2.5 in. thick with circular holes of 3/16 in. diameter. This filter is expendable, cheap, and installed in the tundish to trap any slag and oxide particles, which float on the surface of the pool of metal formed ahead of the filter and are thus prevented from getting into the die. The two views of casting 24 show a clean casting with no surface defects and freedom from porosity in the rim area.

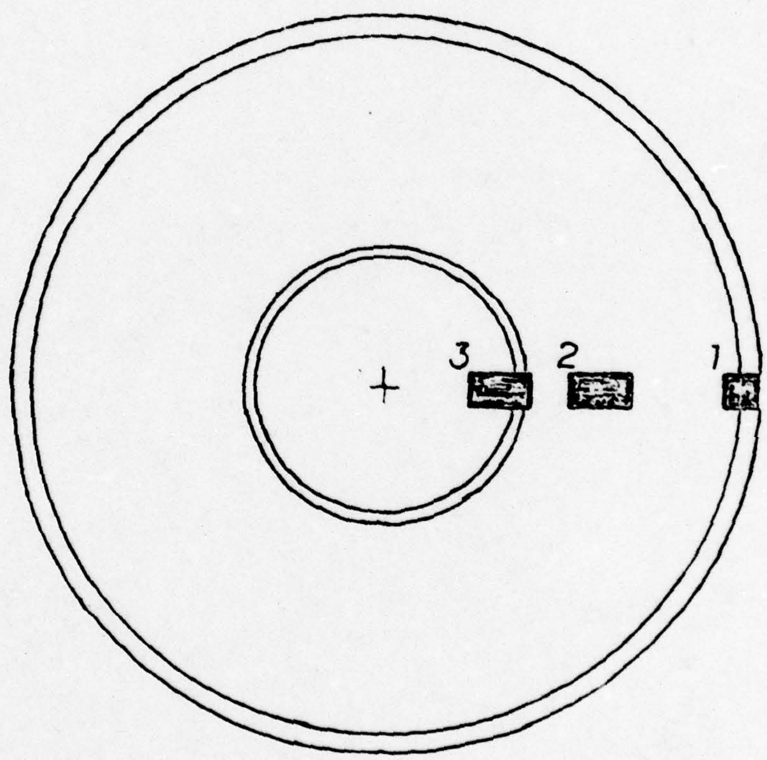
To observe the repeatability of the process the next casting, No. 25 (Fig. 12), was made using the same parameters and turned out to be as good as the previous one.

Castings 17 and 23 were cut, and samples were taken for chemical analysis as shown in Fig. 13 to check the segregation tendency of any alloying element in the aluminum alloy 6061. The analysis is presented in Table 2, and shows no segregation tendency of any consequence. The variations in the chemical analysis are within the experimental and instrumental errors.

UTS and percent elongation were determined on samples from castings 13 and 17. The location of three samples for mechanical testing from casting 17 was the same as shown in Fig. 13.



(a) Cross section



(b) Top view (inside)

Figure 13

Sample Locations for Chemical Analysis and
Mechanical Testing of Forward Dome Castings

Table 2

CHEMICAL ANALYSIS OF FORWARD DOME CASTING SAMPLES

	Casting 13			Casting 17			Casting 23		
Element	1	2	3	1	2	3	1	2	3
Silicon	0.64	0.64	0.70	0.64	0.63	0.66	0.55	0.62	0.60
Copper	0.26	0.26	0.28	0.25	0.22	0.24	0.21	0.25	0.26
Magnesium	0.82	0.80	0.85	0.80	0.79	0.81	0.75	0.80	0.84
Chromium	0.05	0.05	0.05	0.17	0.19	0.16	0.20	0.18	0.19
Aluminum	base	base	base	base	base	base	base	base	base

Table 3

TENSILE PROPERTIES
OF THE FORWARD DOME CASTINGS

Casting No.	UTS, psi	Percent Elongation
13	29,400	20
17-1	26,000	17
17-2	26,100	17
17-3	27,200	13

The results of these tests (Table 3) were quite satisfactory. The mechanical properties of 6061 aluminum alloy sheet and plate in the thickness range 0.50-1.00 in. are given as 22,000 psi UTS and 18% elongation, which compare very favorably with the results obtained on the squeeze casting. The higher UTS is due to the part forged structure which is superimposed on an initially solidified cast structure.

X-ray photographs of casting 25 were taken from different angles to cover the entire casting. All areas appeared to be free from porosity, shrinkage, and cracks except the center, where a few radial cracks were observed.

4.2 Warhead Castings 1 to 4

The melting and casting experience that was obtained in squeeze casting the forward dome using 6061 aluminum alloy was applied in the squeeze casting trials of the PATRIOT warhead. The procedures are described in the following paragraphs.

The dies received from Sarcol were inspected and installed in IITRI's 1000-ton press. The dies were heated to 600°F to develop a thin oxide coating that would prevent sticking and bonding and permit easy stripping of the squeeze cast base. The lower die and the punch were heated to about 350°-500°F by an induction coil and burners, respectively, before squeeze casting. All the die surfaces coming in contact with the molten metal were coated liberally with graphite to prevent bonding.

The 6061 aluminum alloy bar stock was melted in a gas-fired furnace in which an oxidizing atmosphere was maintained to avoid hydrogen absorption. When the melt temperature was reached, the crucible was pulled out of the furnace, brought over to the 1000-ton press, and set into the pouring carriage, which was fitted with a tundish and tilting mechanism. The tundish had a mica filter to trap any floating oxide and impurities that might persist after skimming, which was done right before the metal was poured into the tundish. The carriage was pushed gently towards the press and brought into the right position so that the

downward spout was almost in the center of the lower die. The crucible was now tilted gently to cause the metal to pour without splashing or violent turbulence but rapidly enough to minimize the pouring time. The carriage was retracted, and the press was operated to bring the punch down with the full pressure acting on it. The whole operation from pulling the crucible out of the furnace until the application of pressure on the molten metal took about 2 to 3 min. The dies were kept closed from 30 to 60 sec, after which the pressure was released and the punch moved up with the casting attached to it. Stripping was done by means of four bolts located equidistant on the outer periphery of the punch to exert downward pressure on the rim of the casting when turned down uniformly. The parameters of the four castings made are presented in Table 4, and the pertinent details, problems, and solutions are discussed below:

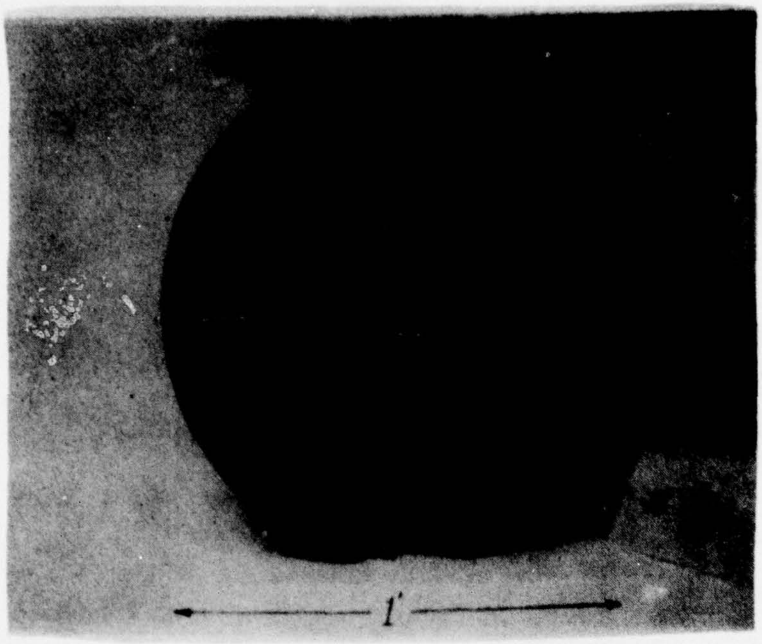
Casting No. 1

Remelt stock was used for this casting. A little excess of the alloy was melted to make sure the die cavity got completely filled after losing an unknown quantity of metal sticking to the tundish and the crucible. The temperature was also kept on the high side to avoid premature freezing that would cause incomplete formation of inner ribs. Higher temperature and the remelt stock combined to give increased gas and shrinkage porosity, which is clearly visible in Fig. 14. A substantial amount of metal was lost due to flash, giving low casting weight. Splashing also caused molten metal to get on the stripper bolts, which had to be cleaned extensively. The stripper bolts had been designed such that they could be turned by putting two nuts on each of them and tightening them against each other. But the torque turned out to be so great that no amount of locking was enough, and the combination of lock nuts kept turning without turning the bolt. Stripping of the casting was finally accomplished by prying on the edges and hammering.

Table 4

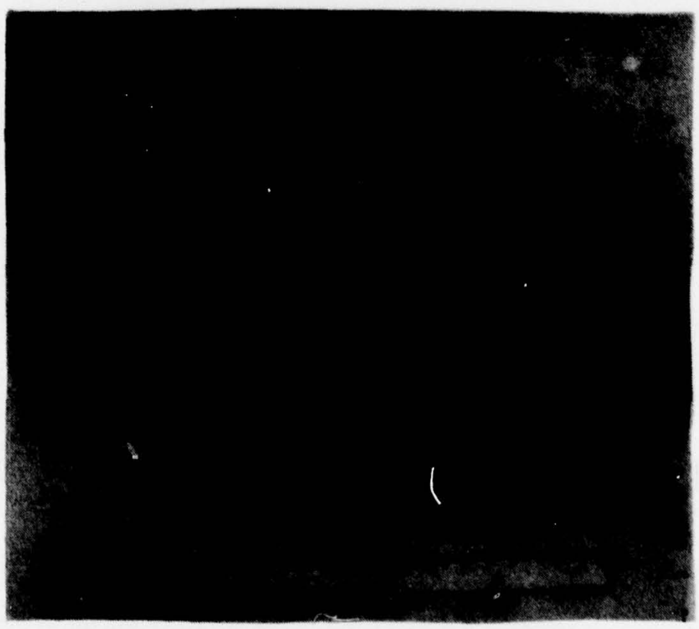
PATRIOT WARHEAD BASE CASTINGS 1 TO 4

Date	Casting No.	Weight of Melt Stock, lb	Melt Temp., °F	Pouring Temp., °F	Press Dwell Time, sec	Weight of Casting, lb/oz	Observation
1/5/79	1	14.5	1650	1600	60	11/10	Gas porosity, inclusions.
1/9/79	2	12.5	1600	1550	45	11/00	Incomplete rib formation due to less metal. Little gas porosity.
1/11/79	3	13.5	1600	1550	30	11/12	Very good casting. Zircon die coating used. One stripper bolt broke.
1/16/79	4	13.7	1600	1550	30	--	Casting stayed in the lower die due to die distortion.



Neg. No. 49803

(a) Top view, showing gas porosity in the rim area.



Neg. No. 49804

(b) Bottom view, with indentation marks due to hammering done to strip the casting from the punch.

Figure 14

Views of PATRIOT Warhead Base Casting No. 1

(c) Enlargement of (a)

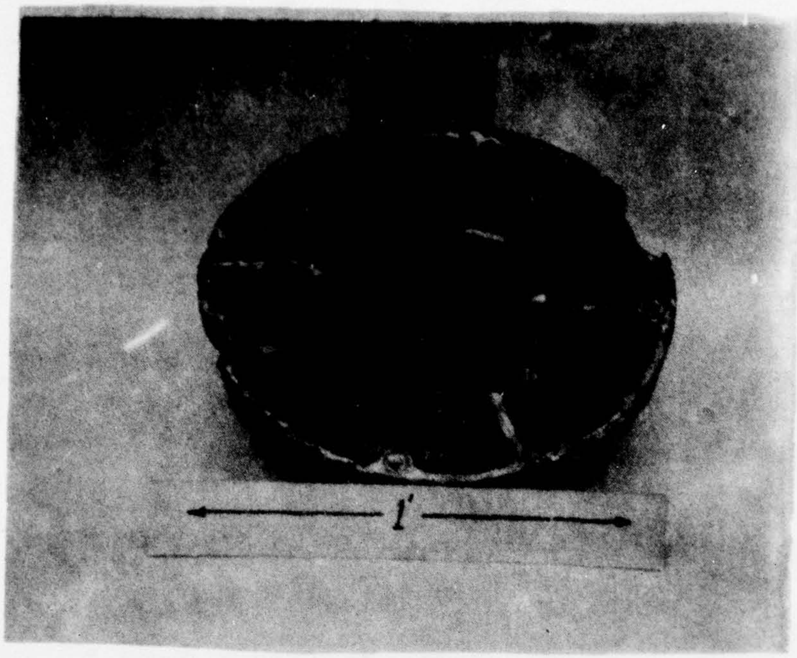
Figure 14 (cont.)

Casting No. 2

Prime 6061 alloy was used for melting, and less weight of alloy than casting No. 1 was melted to avoid splashing out and losing the molten metal during pressure application. Melting temperature was reduced to minimize gas absorption and resultant porosity. The stripping bolts used before were threaded on the entire length except about half an inch at the bottom where pressure was applied on the casting rim to strip it. The lower unthreaded length was a little larger in diameter than the bolt so that the bolt could only be removed by turning it downwards, which was very difficult due to aluminum sticking on the threads. To avoid this problem four hex-head, Grade 8, 4140 high strength bolts were used as stripping bolts, and the gap created towards the lower end was sealed with X-9 refractory plaster to avoid metal penetration in the threads. The exposed threaded part of the bolts was kept covered with asbestos cloth to prevent splash metal sticking to it. The casting turned out to be much better, as shown in Fig. 15, even though difficult to strip. It was found that, in spite of X-9 refractory plaster patching, some aluminum had penetrated into the threads of the bolts and made it very hard to turn.

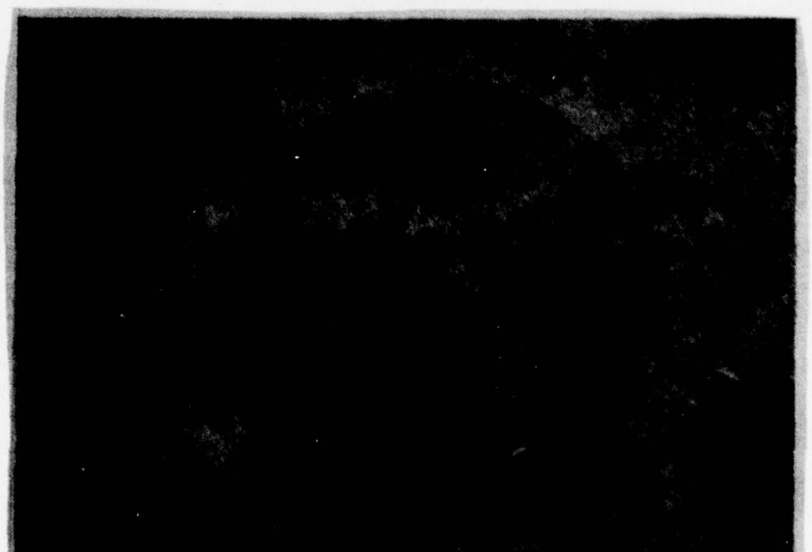
Casting No. 3

During the two previous squeeze casting attempts, it was observed that the longer the delay in stripping, the tighter the casting held onto the punch due to thermal contraction. This time a little more metal than previously was melted, and the press dwell time was reduced to 30 sec. To avoid any delay in stripping, four sockets, each one attached to a ratchet, were kept ready on each bolt before pouring the metal in the die. Right after squeezing when the press ram moved up, the bolts were turned down fast and uniformly, stripping the casting before it cooled down enough to shrink and take a grip on the punch. As shown in Fig. 16, this was a very good casting without any visible porosity, shrinkage, or partially formed ribs. When an attempt was made to clean the bolts by removing them



Neg. No. 49806

(a) Top view. One rib is only partially formed due to insufficient metal.

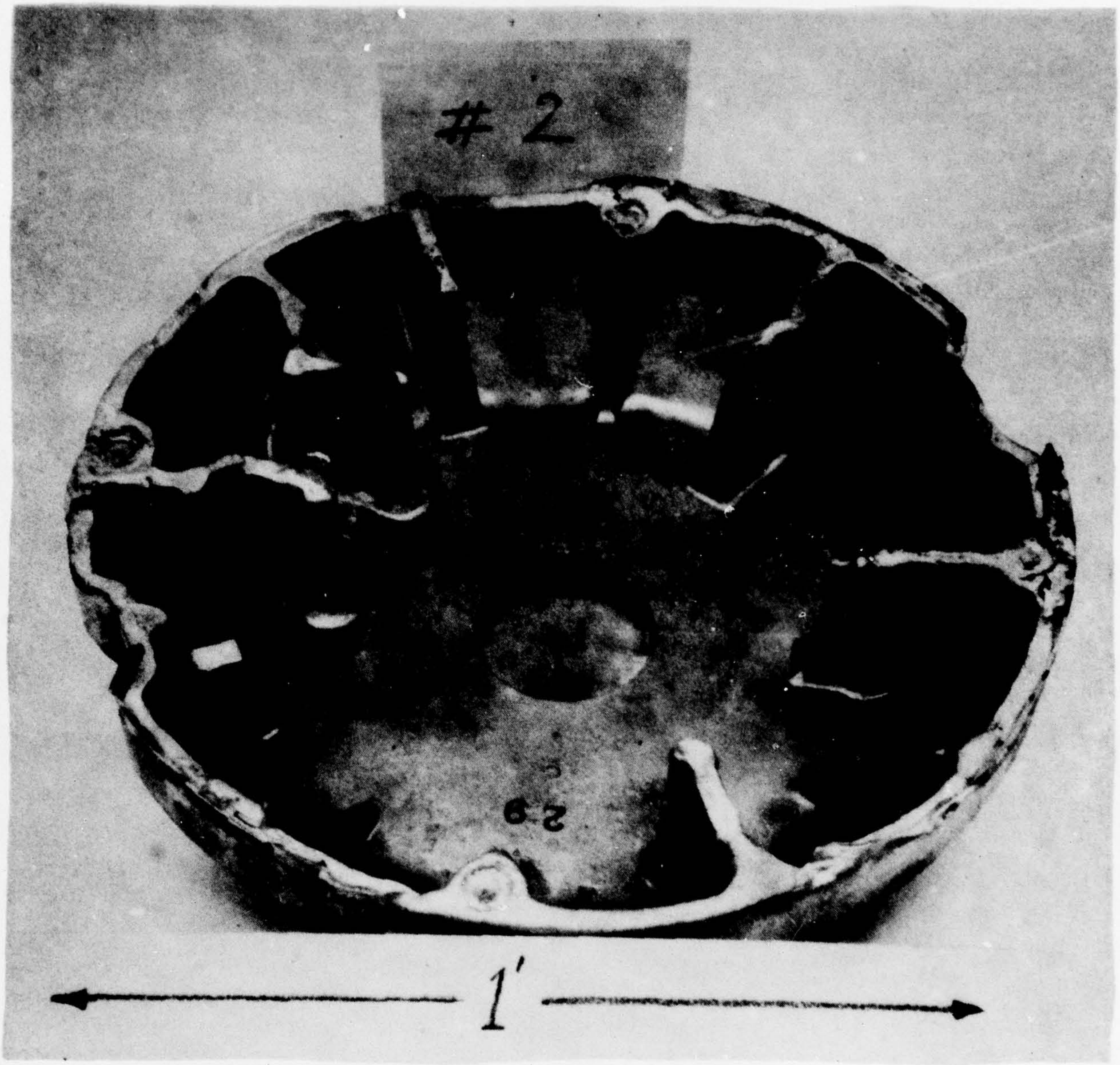


Neg. No. 49807

(b) Bottom view

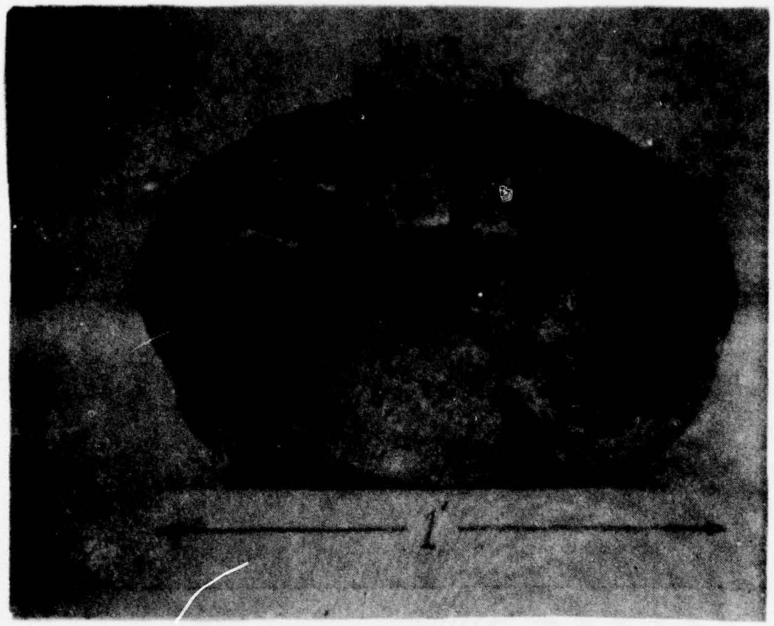
Figure 15

Views of PATRIOT Warhead Base Casting No. 2



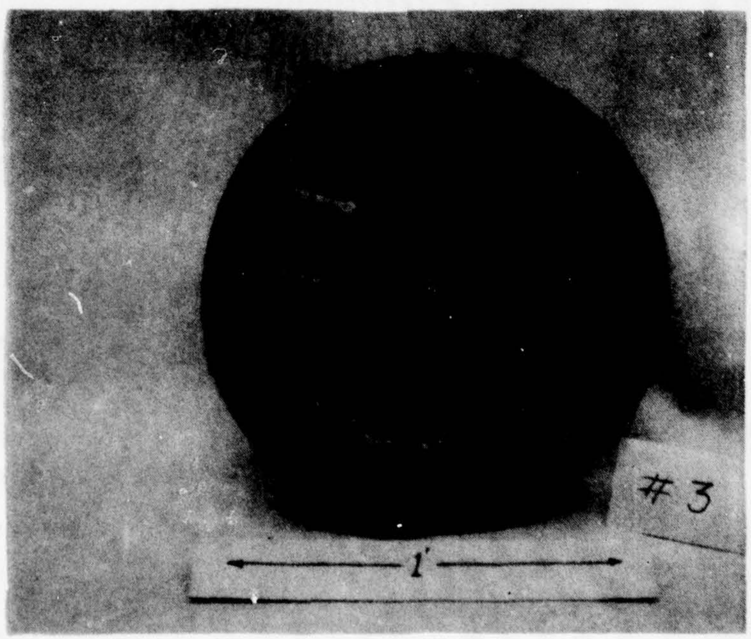
(c) Enlargement of (a), showing the partially formed rib more clearly.

Figure 15 (cont.)



Neg. No. 49809

(a) View showing fully formed complex ribs and no surface defects

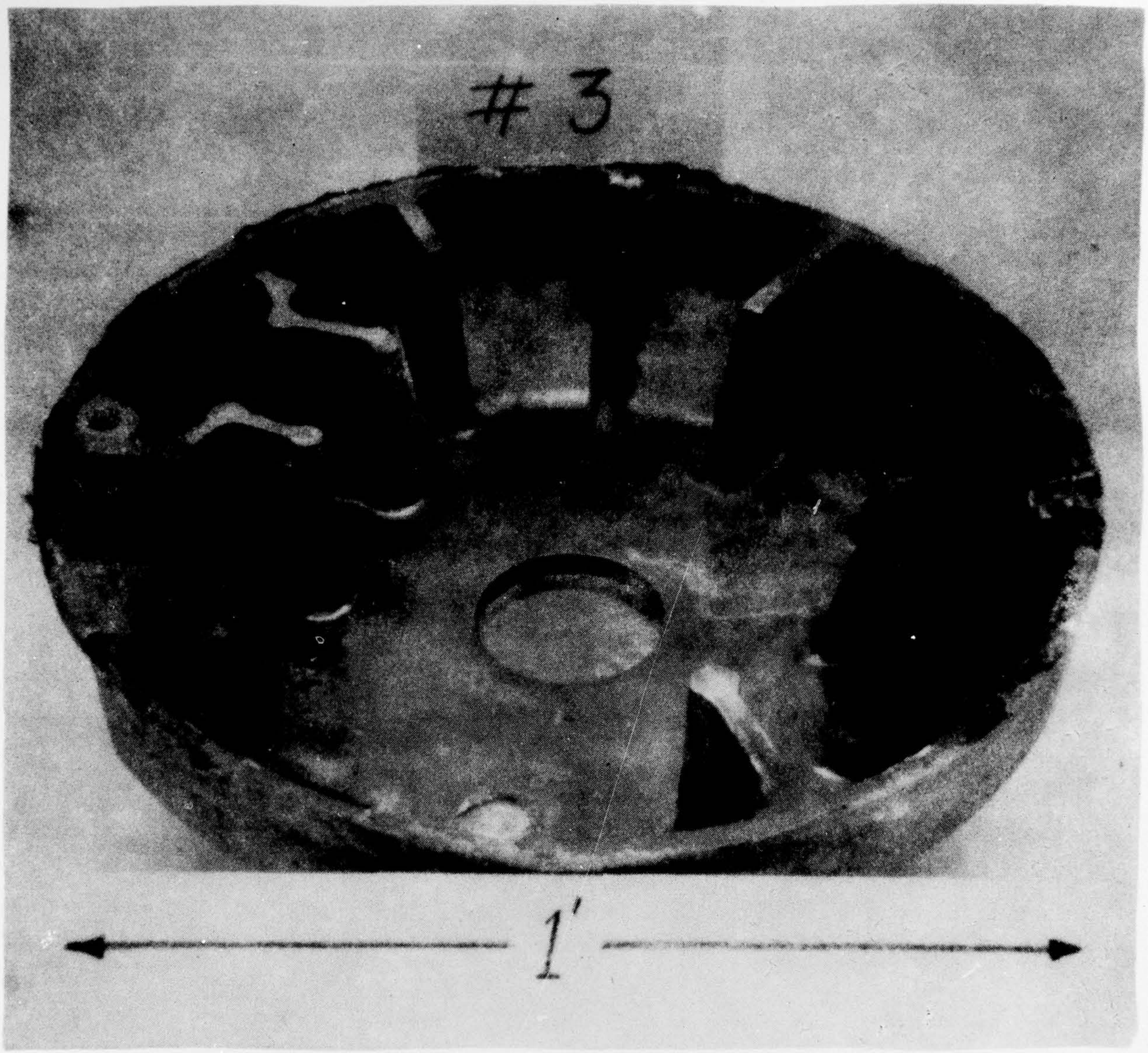


Neg. No. 49808

(b) View directly from the top

Figure 16

Views of PATRIOT Warhead Base Casting No. 3



(c) Enlargement of (a)

Figure 16 (cont.)

for preparation of the next casting, it was found that aluminum had penetrated inside the threads. In an attempt to remove the bolts, one of them broke leaving no other choice but to remove the die and send it to the machine shop to free the bolts.

Casting No. 4

A different design of the stripper bolt was conceived in view of the problem of aluminum penetration. Each bolt was reduced to 1/4 in. diameter over 1/4 in. length on the lower end and threaded so that a cap could be secured to it which would fit in the punch holes with very close tolerance to eliminate aluminum penetration during squeeze casting. This ought to eliminate any molten aluminum penetration in the threaded area of the bolts and make the stripping easier. The punch was received back from the machine shop after cleaning the holes and was installed in the press. The squeeze casting trial was made. After pressure application when the punch moved up, the casting stayed in the bottom die. All attempts to take the casting out failed, and finally the die had to be removed from the press and sent to the machine shop. The only explanation was that the lower die was deformed due to uneven load distribution on the areas which were incapable of bearing it. This conclusion was drawn after a thorough inspection and measurement of die dimensions.

The die was sent back to Sarcol (the original designer and fabricator) for certain design modification and heat treatment.

4.3 Die Modification

After the first four castings, the die set was found to be deformed at the following positions (Fig. 17):

(A) The sides of the top punch plate resting on the lower die

(B) Center of the punch bottom

(C) Two wedges on the lower die

(D) Upper contact surface between the punch and the cavity.

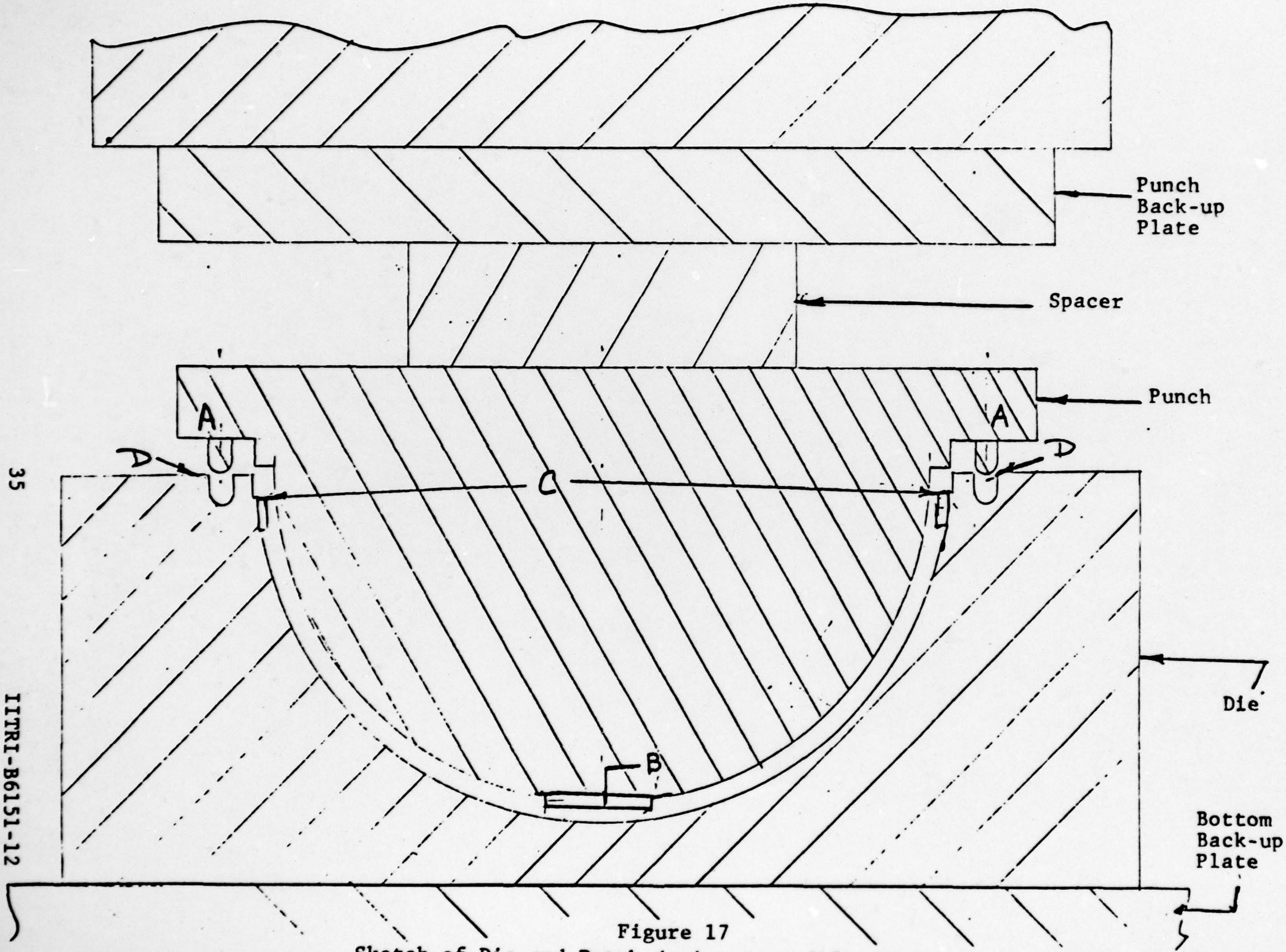


Figure 17
Sketch of Die and Punch (prior to modification)

The punch plate was made very rigid and extended, the center portion of the punch (B) was removed and the two wedges (C) on the lower die were slightly machined, so that the entire pressure could be transmitted directly to the melt. The die set was heat-treated and double tempered. For strengthening purposes a 1 5/8 in. thick plate (H-13) was attached to the upper portion of the punch and rigidly bolted to the punch. These modifications are shown in Fig. 18.

4.4 Warhead Castings 5 to 8

After the die modification more squeeze casting trials were conducted. The parameters of the four castings made are presented in Table 5, and the pertinent details and problems are discussed below:

Casting No. 5

This casting was made using the same parameters as those for casting No. 3. It was observed that all the ribs were not formed due to insufficient metal. Stripping problems were also experienced to a great extent.

Casting No. 6

Sufficient amount of metal was used to ensure complete die filling. It was found that the casting stayed in the lower die. The casting was taken out from the lower die without any difficulty. Some jerking was experienced in the lower die, while taking out the male punch from the cavity after squeezing. This resulted in stripping of the casting in the lower die; some deformation was noticed in the casting bottom, and one rib got cracked. Views of the casting are shown in Fig. 19.

Casting No. 7

This was made in the same way using the parameters of casting No. 3. The casting remained in the top punch in a slightly tilted fashion. It was allowed to stay overnight to observe whether the casting could be stripped off easily in the cold condition. The casting was taken out from the punch with great

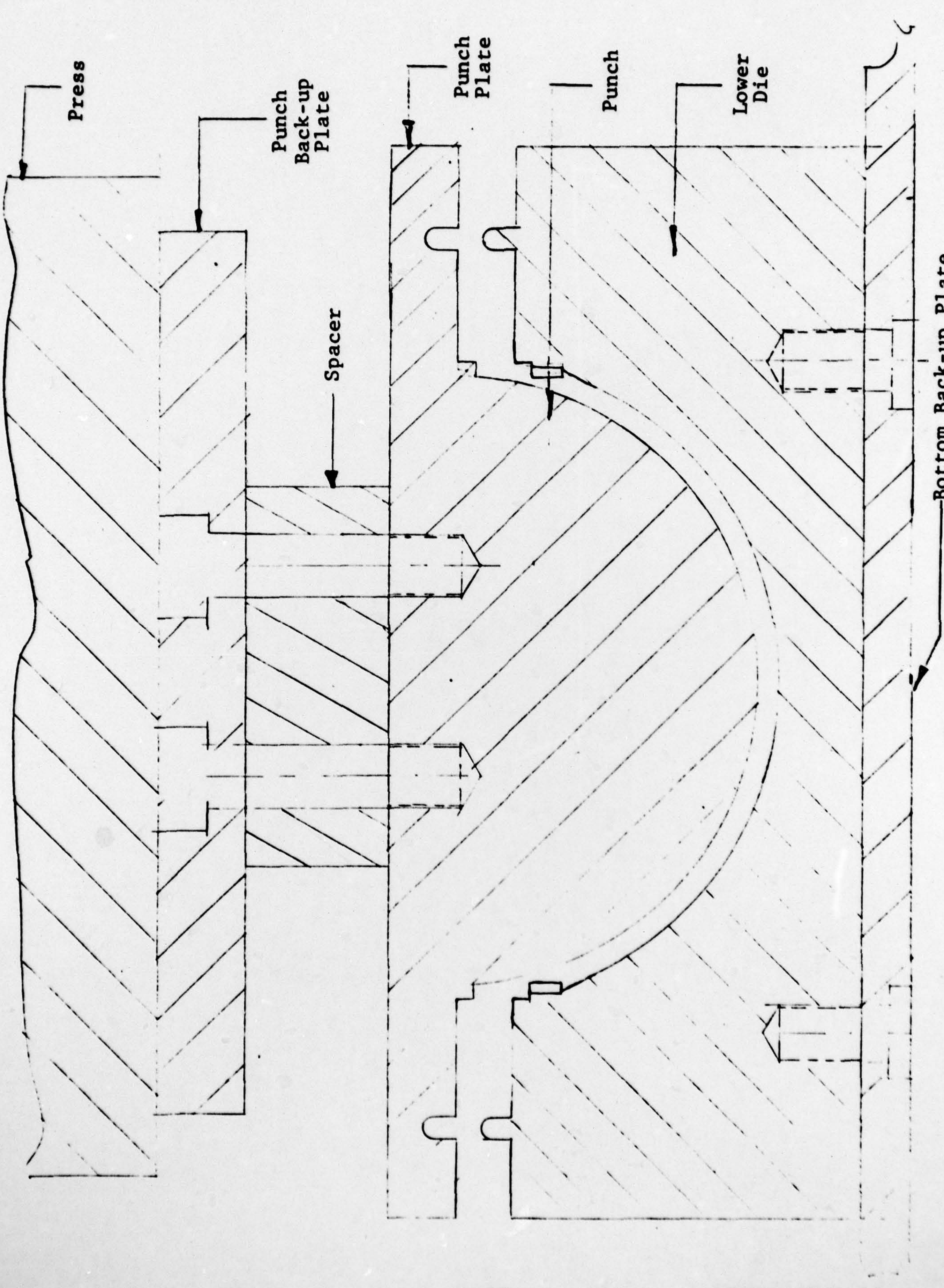


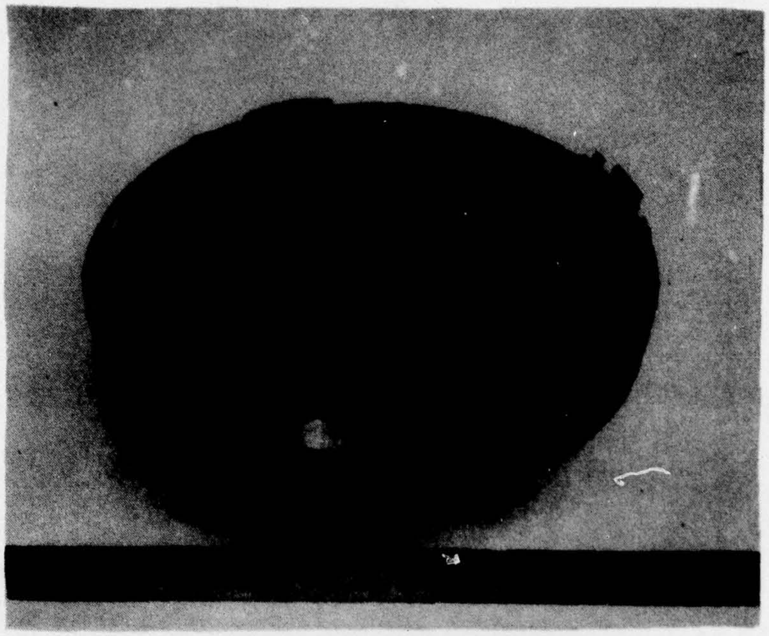
Figure 18
Modification of Die Set

Table 5

PATRIOT WARHEAD BASE CASTINGS 5 TO 8

Date	Casting No.	Weight of Melt Stock, lb,	Melt Temp., °F	Pouring Temp., °F	Press Dwell Time, sec	Observation
3/20/79	5	13.7	1600	1500	40	Incomplete rib formation due to less metal in die cavity (loss of metal in the crucible and pouring through).
3/21/79	6	14	1600	1500	30	Casting stayed in bottom die. Cracks in the rib observed.
3/21/79	7	13.75	1580	1480	30	Casting stayed in the top punch in a slightly tilted manner.
3/22/79	8	13.75	1600	1500	60	Punch support plate was broken, and the punch stuck in the lower die.

Note: Ejection problems were experienced in all cases except casting 6, where the casting stayed at the bottom.



Neg. No. 50191

(a) Inside view

Neg. No. 50192

(b) Outside view

Figure 19

Views of PATRIOT Warhead Base Casting No. 6

difficulty. The stripping mechanism did not work at all. The outside appearance of the casting was good, and all the complex ribs were formed. It was decided to use a thick coating of zircon lubricant in both the dies for easy stripping in the next casting trial.

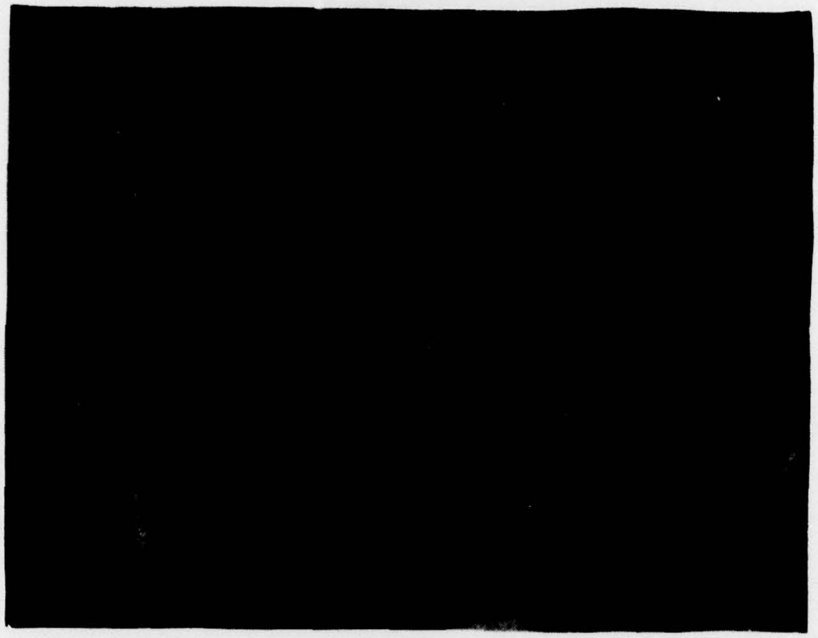
Casting No. 8

A thick coating of zircon lubricant was applied to the die and punch. At the time of squeezing the aluminum in the lower die, the punch plate broke and stayed inside the cavity along with the casting. The punch was taken out with great difficulty. On inspection it was found that the modified punch plate was badly cracked, the punch got damaged, and the lower die was damaged slightly (Fig. 20).

Stripping of the casting from the punch was considered the only problem in making the casting. The complex ribs were well formed. The purpose for the trials conducted thus far was to ensure that the castings could be stripped from the punch. No parameters were established to control the metallurgical characteristics.

A series of discussions were held with the program monitors upon their visit to IITRI on March 29 and 30, 1979. Castings 6 and 7 were cut into two different sections to check on their integrity. Some metallurgical defects were noticed such as shrinkage porosity, segregation, etc. Representative pictures of the cut sections are shown in Figs. 21, 22, and 23.

It is evident that undesirable metallurgical defects can be eliminated by improved melting technique with proper control of melting and pour temperatures.



Neg. No. 50173

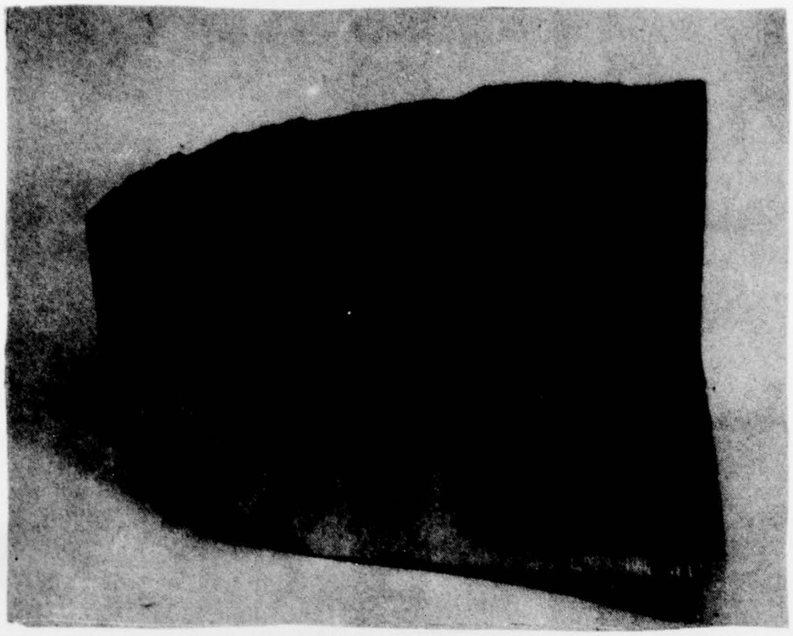
(a) The damaged lower die. Punch plate broke and stayed inside the die cavity along with the casting.

Neg. No. 50174

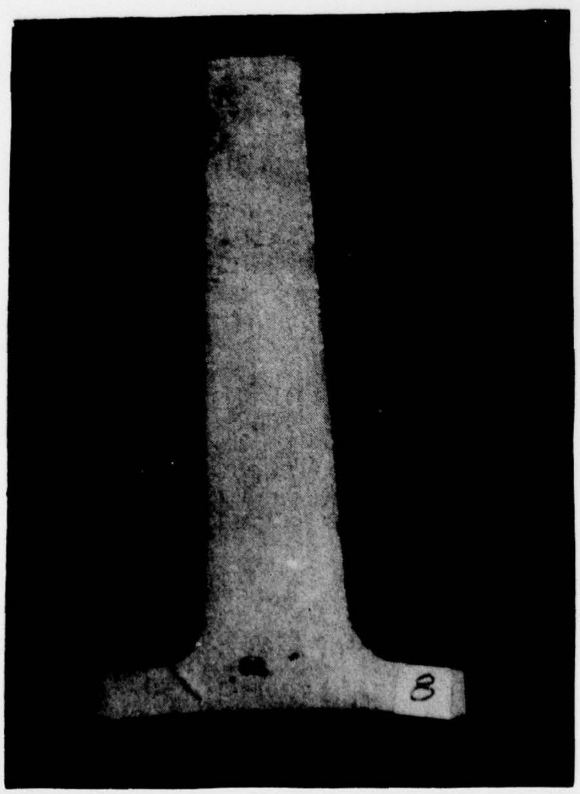
(b) The cracked punch support plate

Figure 20

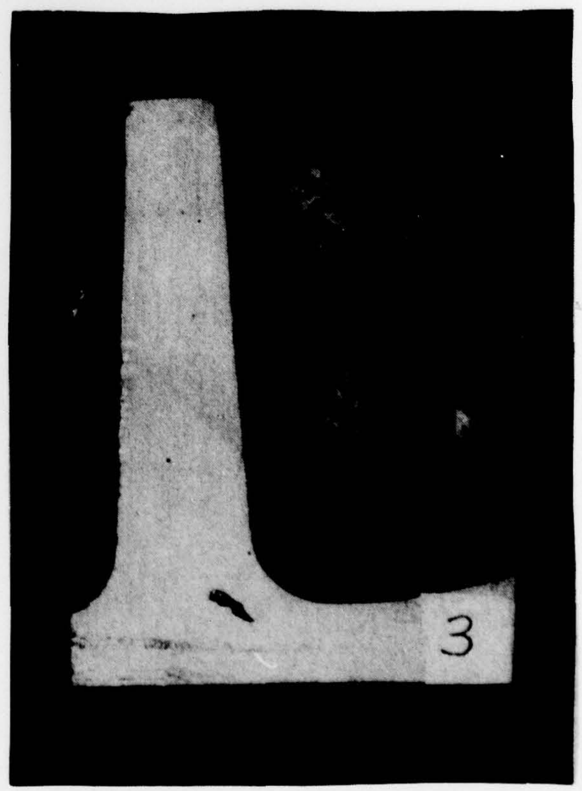
Damaged Lower Die and Cracked Punch Support Plate



Neg. No. 50201
(a)

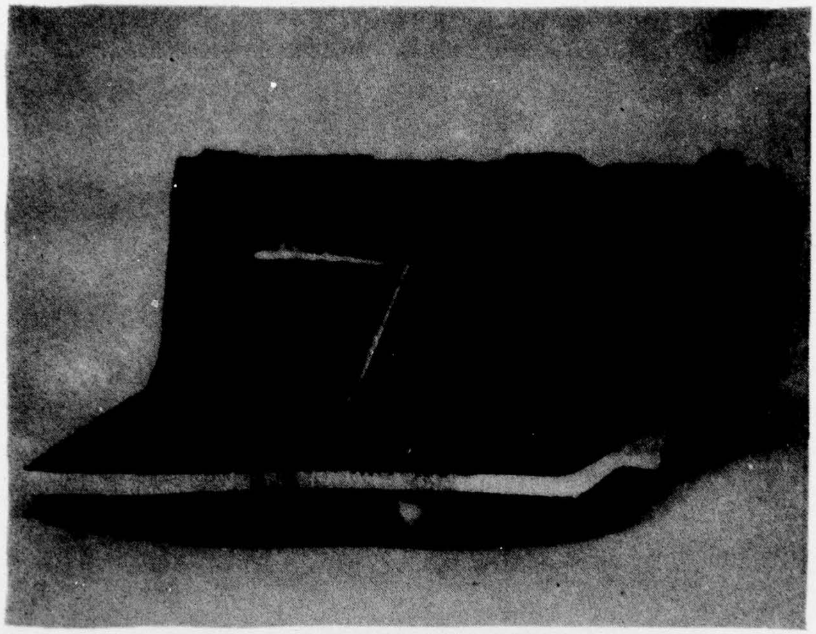


Neg. No. 50210
(b)



Neg. No. 50215
(c)

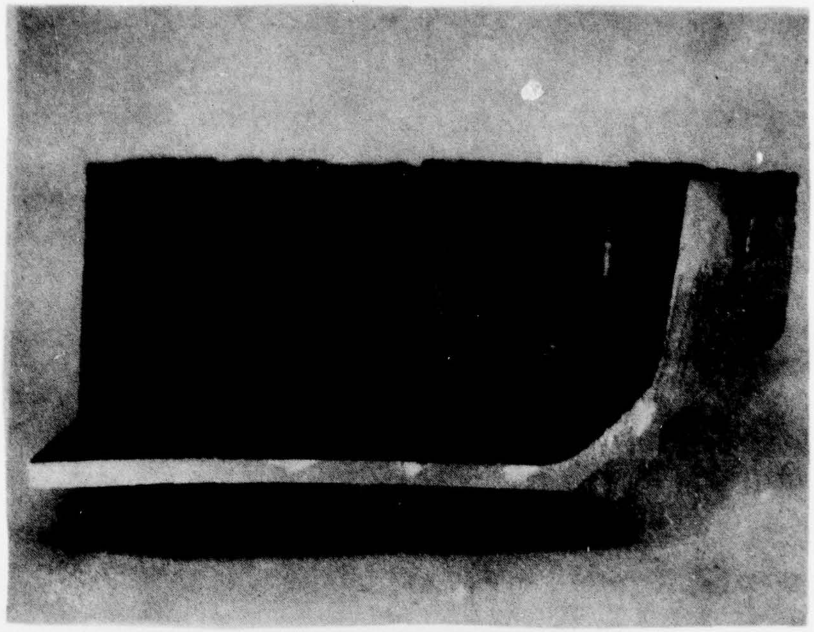
Figure 21
Cut Sections of PATRIOT Warhead Base Casting No. 6, Showing Shrinkage Porosity



Neg. No. 50199

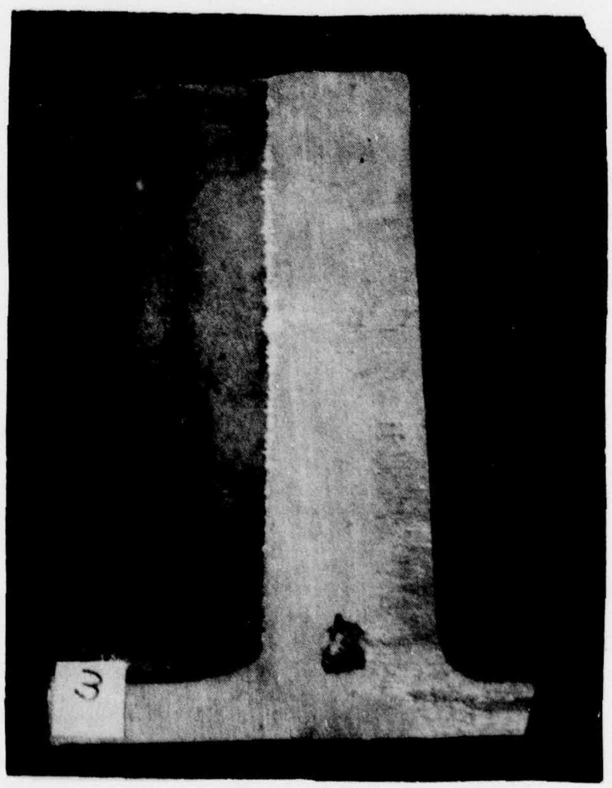
Figure 22

Cross Section of PATRIOT Warhead Base Casting No. 6, Showing Absence of Shrinkage Porosity



Neg. No. 50200

(a)



Neg. No. 50209

(b)

Figure 23

Cut Sections of PATRIOT Warhead Base Casting No. 7, Showing (a) Shrinkage and (b) Gas Porosity

5. CONCLUSION

It was observed that the complicated ribs did form properly. In the course of this work, severe problems were encountered in the ejection mechanism. The undesirable metallurgical defects could be eliminated by improved melting techniques with proper control of melting and pouring temperatures.

To fulfill the program objectives, the design of a new ejection mechanism is essential, along with some modification in the tooling for easy stripping of the squeeze-cast part.

REFERENCES

1. V. M. Plyatskii, Extrusion Casting (English ed.), Primary Sources, New York, 1965.

2. J. C. Benedyk, "Squeeze Casting: Combining Forging Properties in a Large Casting," Paper No. 72-DE-7 presented at the ASME Design Engineering Conference and Show, Chicago, May 8-11, 1972.

3. S. Chatterjee and A. A. Das, "Some Observations on the Effect of Pressure on the Solidification of Al-Si Eutectic Alloys," The British Foundryman, Vol. 66, April 1973, pp. 118-124.

4. K. M. Kulkarni, "Hybrid Processes Combine Casting and Forging," Machine Design, Vol. 46, No. 11, May 2, 1974, pp. 125-128.

5. K. M. Kulkarni, D. Stawarz, and R. B. Miclot, "Feasibility of Squeeze Casting Ferrous Components," Proc. NAMRC-IV (N. Am. Metalworking Res. Conf.), May 1976, pp. 58-66.